CONICAL SCAN IMPACT STUDY

Volume 2: Small Local User Data Processing Facility

Donald H. Ebert
P. E. Chase
Jack Dye
W. C. Fahling
R. H. Johnson

Bendix Aerospace Systems Division
Ann Arbor, Michigan 48107

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16. Abstract

Studies were performed to determine the impact of a conical scan versus a linear scan multispectral scanner (MSS) instrument on a small local-user data processing facility. User data requirements were examined to determine the unique system requirements for a Low Cost Ground System (LCGS) compatible with the Earth Observatory Satellite (EOS) system. Candidate concepts were defined for the LCGS and preliminary designs were developed for selected concepts. The impact of a conical scan MSS versus a linear scan MSS was evaluated for the selected concepts. It was concluded that there are valid user requirements for the LCGS and, as a result of these requirements, the impact of the conical scanner is minimal, although some new hardware development for the LCGS is necessary to handle conical scan data.

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PREFACE

OBJECTIVES

The main objectives of this study were the determination of the impact of a conical multispectral scanner (MSS) versus a linear MSS on a small local user data processing system. Secondary objectives were the definition and evaluation of candidate Low Cost Ground Station systems to meet the local user requirements.

SCOPE

The study defined a Low Cost Ground Station Concept capable of meeting local user requirements for EOS data acquisition and processing. Candidate LCGS designs were defined and evaluated in terms of performance and cost. The conical scan impact on selected LCGS systems was evaluated.

CONCLUSIONS AND RECOMMENDATIONS

Low Cost Ground Stations capable of providing EOS data to small local users are feasible and practical. The impact of the conical scanner on the LCGS is that low-cost image output devices must be designed and developed for conical scan data whereas such devices exist for linear scan data.

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SECTION 1

INTRODUCTION AND SUMMARY

1.1   CONCEPT OF A LOW-COST GROUND STATION FOR EOS

The concept of a low-cost Ground Data Station for EOS is based on per-
forming selective data preprocessing and directive data transmission functions
onboard the EOS satellite.   These onboard functions are performed to allow
the receiving, recording, and processing functions of a ground station to be
performed by equipment of much lower cost than the corresponding equipment
required in national/regional facilities for full EOS data.

This concept is illustrated by the functional diagram of Figure 1-1.   The
upper functions shown in this diagram include the subsystems of EOS pertin-
ent to the low-cost ground station (LCGS).   In each of these subsystems the
function or equipment necessary to the LCGS are shown in solid boxes while
the functions shown in dashed boxes may be performed by the same subsystem
but are not directly related to the LCGS.   The lower position of Figure 1-1
shows the specific subsystems of the LCGS and the two related functions of
the EOS control center.

This study defines an LCGS concept related to an EOS linear multi-
spectral scanner (MSS) and then evaluates the impact on the LCGS of other
EOS MSS sensors, including a conical scanner and the High-Resolution Point-
able Imager (HRPI).   The output of the MSS sensor is a high data rate digitized
video signal covering a 185-kilometer swath width and composed of seven
spectral bands with geometric resolution of 30 x 30 meters (in most bands)
and radiometric resolution equivalent to 6 bits.   The total data rate of this
sensor averages 106 (10^6) bits/second.

The onboard processor operates to reduce the swath width of the data
to be transmitted, or to reduce the number of channels transmitted, or to
reduce the spatial resolution, or to transmit the information over a longer
time, or a combination of these as selectively programmed by the EOS con-
trol center.   The result of this selective processing is a significantly reduced
data rate on the order of 1 to 10 (10^6) bits/sec.

These data are received and relayed by the communications system to
the LCGS.   The communications system directs the transmitted energy of the
selected data to the location of the LCGS, using either a fixed or pointable
antenna.   The spacecraft antenna for the LCGS link has a gain higher than that
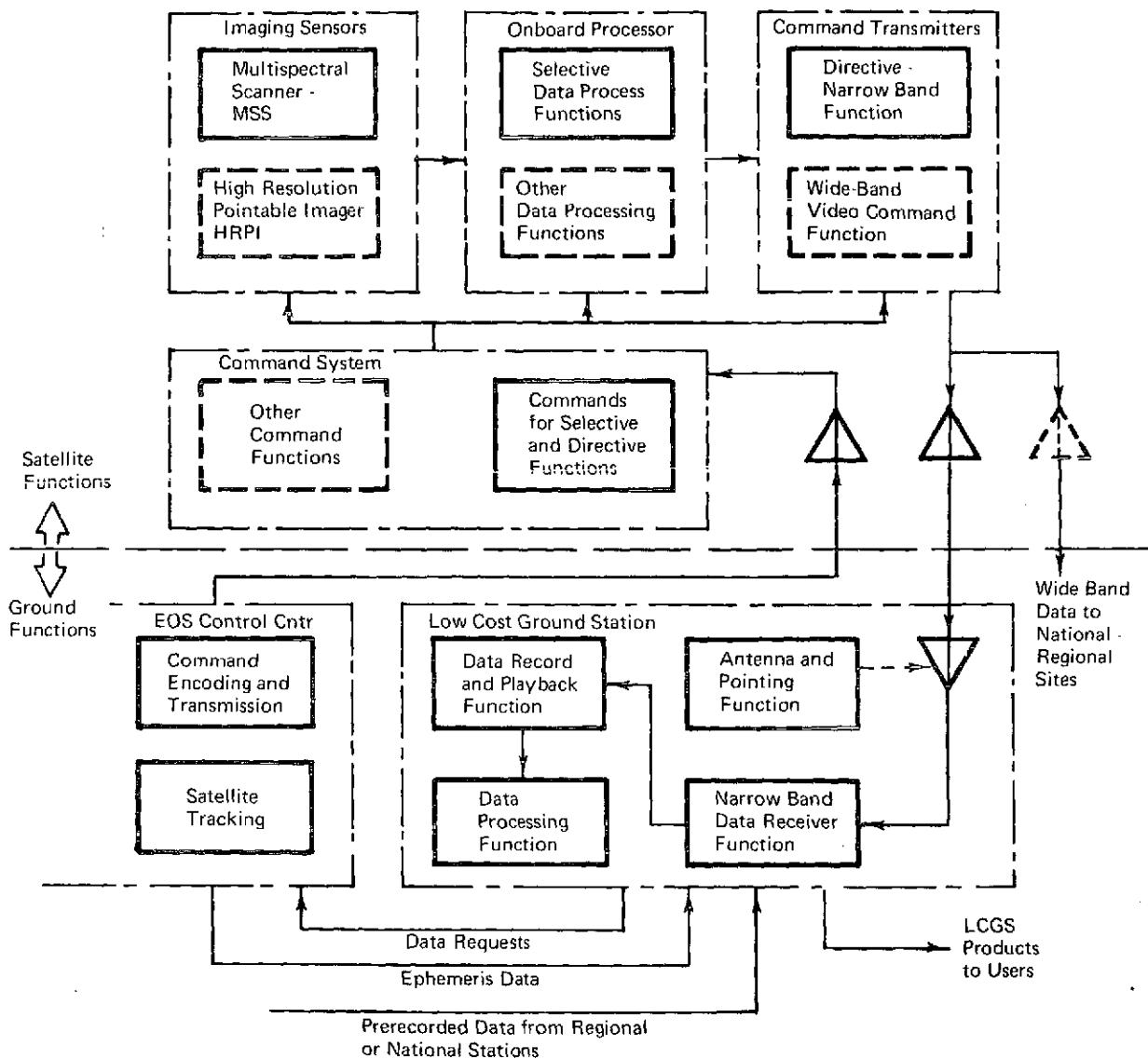
Figure 1-1 Functional Diagram: Concept for Low-Cost EOS Ground Station

of the antenna for the link to the national/regional center. This higher gain in the spacecraft end of the EOS-to-LCGS link allows the antenna and receiver of the LCGS to be further reduced in performance and, consequently, in cost.

The LCGS itself is made up of four functions: (1) antenna and antenna pointing functions, (2) receiving function for the narrow band data, (3) data recording and playback function, and (4) data processing function. Each function may feasibly be implemented at very low cost dependent on the selective and directive functions performed in EOS and the types of products prepared for LCGS users. As an example for each function:

- A manually pointed fixed antenna would allow reception during the time EOS is transmitting data from the selected ground coverage.

- A simple FM-PCM receiver could be used dependent on sensitivity and bandwidth required for the directed narrow-band data.

- A dual-mode High Density Digital Tape (HDDT) recorder would allow recording of the relatively narrow-band data from the LCGS receiver and playback of these data and also HDDTs from national or regional EOS data centers for processing.

- The use of low-cost and self-contained digital processing with mini-computers, low-cost moving window displays, and hard copy recorders.

The LCGS also requires some data interchange with the EOS control center as shown in Figure 1-1. The LCGS data requests indicate where the LCGS will be located and what coverage is required, and are the basis for commands which are formatted and sent to EOS to result in the selection of these data and their direction to the LCGS location. In turn, the LCGS requires EOS ephemeris predictions to plan and locate its operations and manually point its antenna.

The LCGS also offers the possibility of two other important capabilities: (1) mobility and (2) direct accessibility by local users who are familiar with the local area and are most capable of training for automated interpretation or analysis for manual interpretation.

1.2 BASELINE SYSTEM

In investigating conical and linear scanners to evaluate their comparative impact on ground data processing and recording operations, it is useful to define a baseline system. Indeed, it is essential to establish baseline scanners if meaningful cost comparisons are to be made. The baseline system described in this section includes the spacecraft and conical and linear scanners.

The EOS spacecraft baseline parameters used in this study are given in Table 1-1. The orbital characteristics listed are convenient values within the range of values found in the EOS Definition Phase Report and scanner sensor study reports. Selection of different orbital characteristics over this range would not seriously impact the ground systems and has negligible effect on comparative studies of conical and linear scanner data processing. The tracking and attitude control characteristics represent data received from the EOS Program midway in this study. The conical versus linear scan impact has some sensitivity to attitude control and/or measurements; however, relaxing these values to be equivalent to the ERTS system would not alter the significant comparative results of this study.

Table 1-1

EOS Spacecraft Baseline

Orbit: 735 kilometers at Equator
        Sun Synchronous
        98.35° Inclination

Attitude Control:
 	
    Pointing Accuracy $< \pm 0.01°$
 	
    Pointing Stability (geocentric)
 	
            Average Rate Deviation $< \pm 10^{-6}$ degrees/second
 	
            Attitude Deviation
            1. Up to 30-second Period $< \pm 0.0003°$
            2. Up to 20-minute Period $< \pm 0.0006°$

Tracking Accuracy:
 	
    Position Along Track   30 meters
 	
    Position Cross Track   50 meters

The baseline conical scanner is derived from the January 1973 Design Study Report on the Honeywell Seven-Band Scanning Radiometer. The essential parameters used are shown in Table 1-2. The baseline specifies a cone axis that produces a conical scan line passing through the spacecraft nadir and concave forward as shown in Figure 1-2, line a.

Table 1-2

Conical Scan Baseline

Orbit: 735 kilometers at Equator
Sun Synchronous, 98.35° Inclination

Swath width: 185 kilometers

Cone semi-angle: 17.08°

Cone axis: 17.08° forward from local vertical

Bands 1-6: 8 scan lines per sweep
43 μ rad x 43 μ rad IFOV
5,722 pixels per scan line

Band 7: 2 scan lines per sweep
172 μrad x 172 μrad IFOV
1,430 pixels per scan line

Offset pointing: ±20° lateral from local vertical in
5° steps

Quantization levels: 6 bits per pixel

Duty Cycle: 80%

The concave forward conical scan geometry is chosen because it requires only about 46% of the memory required by the equivalent convex forward scan geometry when converting the conical scan lines to linear form in a computer. The comparative geometry of concave and convex forward scan is shown in Figure 1-3. This result is independent of whether or not the scan cone axis passes through the spacecraft nadir. Scanning through the spacecraft nadir was chosen because it produces the minimum geometric distortions from terrain effects. Other than these exceptions, the effects of scanning as shown in Figure 1-2, lines a, b, or c, are equivalent in terms of impact on ground data processing.

S/C Motion

Line c
Concave Forward
Cone Axis through Nadir

Line a - Baseline Scan
Concave Forward
Scan through Nadir

S/C
Nadir

Line b
Concave Backward
Cone Axis through Nadir
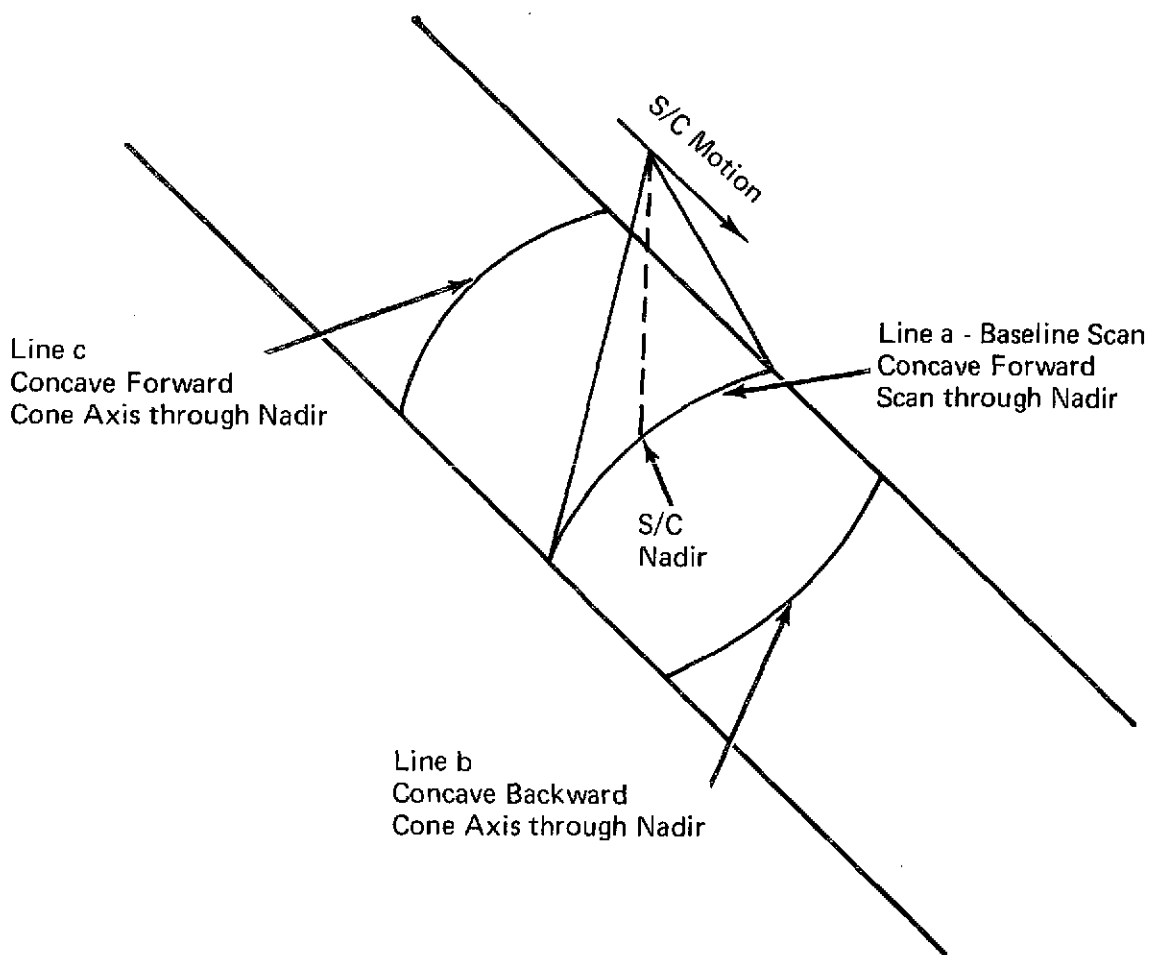
12136-1

Figure 1-2 Baseline Conical Scan Geometry

S/C
Motion

Present Input Conical Scan
Line from Tape

B   B

Present Output Linear
Scan Line

Data Stored from Previous
Input Conical Scan Lines
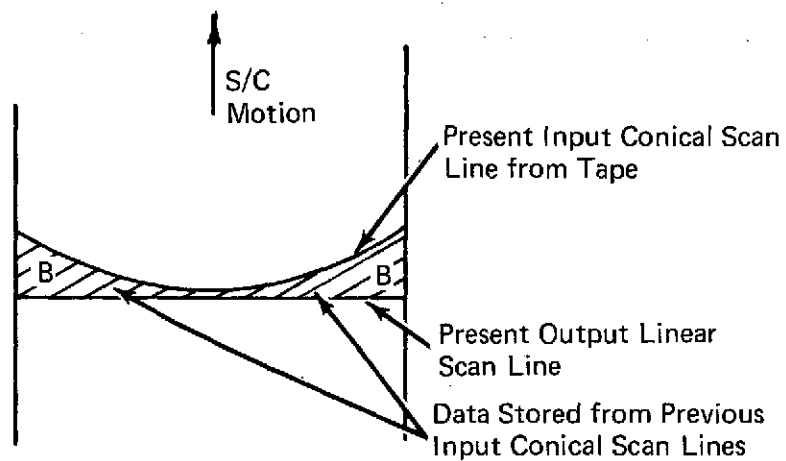
a.   Concave Forward Scan

Note: Area B is Less Than
         50% as Large as
         Area C

S/C
Motion

Present Input Conical Scan
Line from Tape

C

Present Output Linear
Scan Line

Data Stored from Previous
Input Conical Scan Lines
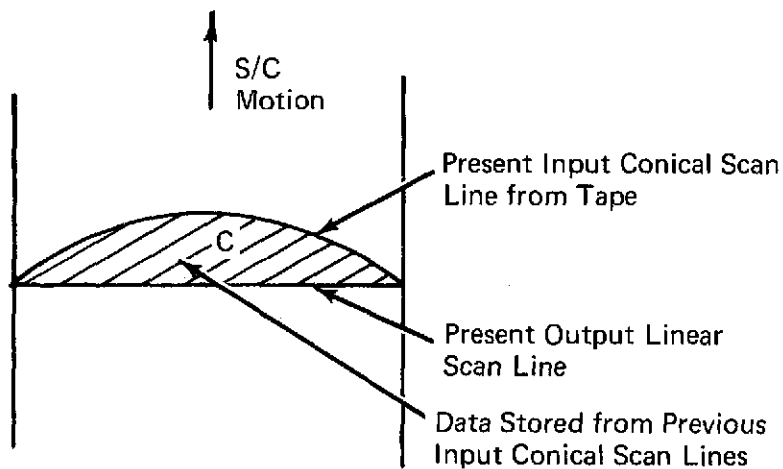
b.   Convex Forward Scan

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Figure 1-3 Data Storage Requirements for Conical Scan Linearization

The baseline linear scanner, described in Table 1-3, is a contrived set of characteristics to permit comparison of the baseline conical scanner with a linear scanner similar in details important to the comparison of data recording and data processing. In this way, the elements of scanner design that have no bearing on geometric, radiometric, or aperture effects are removed from consideration.

Table 1-3

Linear Scan Baseline

Orbit: 735 kilometers at Equator
       Sun Synchronous, 98.35° Inclination

Swath width: 185 kilometers

Half-Scan Angle: 7.22°

Offset pointing: ±20° lateral from local vertical in
                 5° steps

Duty Cycle: 80%

Quantization levels: 6 bits per pixel

Bands 1-6: 8 scan lines per sweep
           43 x 43 μrad IFOV
           5,861 pixels per scan line

Band 7: 2 scan lines per sweep
        172 x 172 μrad IFOV
        1,465 pixels per scan line

SECTION 2

LOCAL USER SYSTEM REQUIREMENTS

2.1 GENERAL REQUIREMENTS

To attain acceptance by the user community, a small local user ground data system must be low in cost, provide data directly to the user in a form desired by him, provide more timely data than obtainable from the General Central Data Processing (GCDP) Facility, and permit the local user to operate interactively with the system for data collection and processing. The principal challenge to the designer of such a system is providing useful data at a low enough cost to permit or justify system acquisition or utilization by relatively low volume data users. Different potential local users have various needs in terms of area of coverage, frequency of coverage, number and wavelengths of spectral bands, resolution, and data accuracy, and that data are of different levels of economic worth to the users. This section describes the results of a brief survey of local user data requirements and translates them into local user system requirement guidelines. These requirement guidelines are in turn translated into the Low Cost Ground System (LCGS) design described in subsequent sections of this report.

2.2 APPLICATIONS REQUIREMENTS

For the purpose of this study, it is recommended that the EOS spacecraft will transmit data to two different types of ground receiving and processing systems, the GCDP and the LCGS. The LCGS provides unique characteristics in relationship to the centralized station, and its applications will be those which take advantage of these unique characteristics. Specifically, the LCGS is unique in four ways:

1. The LCGS will provide a direct interface between the EOS user, the EOS image data, automated equipment to analyze these data, and personnel trained and experienced in helping to analyze and apply EOS data. Comparatively, the EOS user who is serviced by the centralized station receives standard film or digital products from the mail and must provide at least some degree of specialized knowledge and equipment to interpret or analyze EOS data.

2. The EOS image data and the products resulting from the LCGS-assisted user analysis of these data are available in a time scale ranging from minutes to a few hours. Comparatively, products

from the centralized facility will require weeks and perhaps months to reach the local user. For the standard products from the central station, the time to analyze these data and produce output products is added.

3. The video data transmitted to the LCGS are inherently more secure than the data transmitted to a receiver/antenna that services a centralized processing system. This security results from the directionality of the antenna pattern for the link to the LCGS and from the user-specified editing. As a result, it will be difficult to receive and reconstruct these data at a site far removed from the location of the LCGS.

4. The LCGS provides edited data. Depending on the design of the LCGS, these data may be edited in terms of area coverage, number of channels, spatial resolution, or a combination of these. The user of products from the centralized facility receives standard unedited products, e.g., 185 x 185 km, seven spectral bands, and 30-meter pixel samples.

The LCGS applications therefore include those which require one of the first three characteristics, which are attributes of the LCGS:

1. Direct user interface.

2. Immediate data availability.

3. Security or privacy.

These applications, however, are restricted by the requirement that they be satisfactorily performed by data which have been edited according to the fourth characteristic, which is a restriction of the LCGS:

4. Selective Scene Data.

Analysis indicated that there are abundant applications requiring any one of the three attributes of the LCGS and which are compatible with the restrictions of characteristic 4, selection of only part of the scene data available in EOS. Some examples are discussed below.

2.2.1 Local Agricultural Surveys

Local agricultural surveys for crop identification, yield forecast, and survey to detect nutritional, irrigation, or infestation anomalies will typically require all spectral channels and full resolution. They may be restricted to local areas, perhaps county size, where the crops of interest are known to be grown. These applications are significantly aided by attribute 1 (direct user interface) as the county agent or large farmer is either necessary to or can significantly improve the quality and value of either automated or manual data interpretation.

The timeliness attribute (2) of the LCGS is also very important to these agricultural applications. If there is a nutritional deficiency or a disease infestation, clearly the value of this information rapidly decreases and the data may be worthless within a week or a month after the deficiency is observed. The sampling due to the repetitive cycle of the EOS orbit (nominally 18 days) may preclude observation of a developing anomaly at the best time, but when the EOS observation is made, the resultant data are current and valuable. In this sense, EOS provides an opportunity to observe on a cyclical basis, subject to weather and aided possibly by the offset pointing capability of the MSS sensor in EOS.

2.2.2 Emergency Responses to Natural Disasters

The timeliness offered by the LCGS is vital to applications involving natural disasters such as floods, hurricanes, and earthquakes. The potential of EOS is, however, limited by the approximately 18-day cycle of a satellite in low earth orbit with 185-km coverage, although EOS offers significant improvements over ERTS in this respect — the ability of EOS to offset the MSS sensor pointing by $\pm 20°$ from the nadir. This offset effectively provides three or four looks at a particular ground location during an 18-day cycle.

2.2.3 Ocean and Lake Surveillance

The timeliness attribute (2) is very important to potential applications involving ocean and lake surveillance for ice, pollution, fishing indicators, and other transient phenomena. The ability to interface directly with a knowledgable interpreter or data user may also upgrade the value of the EOS application. Each has individual requirements on data selection.

Ice surveillance of the Great Lakes, for example, can extend the shipping season of inland ports such as Detroit, Chicago, and Duluth. The information needed must be timely and must cover at least the shipping channels and probably as much of the width of each lake as possible. However, the data need only be from a thermal band of the MSS scanner.

An example of pollution surveillance is surveillance for oil slicks or dumps from shipping. The US Coast Guard is currently beginning operations in this type of surveillance with seven airborne systems, each with two line scanners (one in the UV and one in the IR spectral bands). The EOS data, selected to cover coastal and shipping regions and to provide one or more visible bands with the IR band, will potentially augment this airborne capability if the data can be provided on a timely basis to knowledgeable Coast Guard interpreters.

Fishing operations may be aided by either visible or thermal bands to detect algae upwellings or thermoclines associated with locating the best offshore positions for commercial fishing. The data may be edited in these cases by summing pixels in the satellite to produce less transmitted data, but with more usable bits per data byte providing increased radiometric sensitivity for the large area targets.

2.2.4   International Applications

NASA's present doctrine for use of the ERTS satellite, in regions where a country is in the coverage radius of an ERTS receiving site owned by a second country, is to only turn on the satellite where there is a signed agreement between both countries. On a long-term basis, for EOS, and where the receiving, recording, and processing sites are proliferated, this approach will not be adequate. For nationalistic, competitive, and exploitive reasons, the privacy or security of data over each country's territory is important for ERTS and will become much more important for EOS where resolution and spectral capabilities are improved.

The use of the full data transmission mode to a regional site in EOS (assuming that this does not use a programmed directional antenna) allows any receiving site within the horizon coverage of approximately ±2,800 km to receive the same data. A country that invests in a receiving site to obtain EOS data on its own terrain therefore makes that transmission available to its neighbors and perhaps its economic competitor for that region.

The LCGS concept provides an alternate way for this country, par-
ticularly a small and possibly more exploitable country, to obtain needed data
with privacy. With consideration of the inherent capability for privacy in the
directional transmission to the LCGS, it can be used not only for the applica-
tions which require direct user interface and immediate data availability as
in the three preceding examples, but may be used for other applications such
as geology or land use that ordinarily may use the standard products from a
centralized regional station.

A summary of the rationale relating various EOS applications to the
LCGS or to the central stations products is summarized in Table 2-1.

Table 2-1

LCGS Attributes & Limitations in Various Applications

User/Application	LCGS Characteristics			
	Attributes			Limitation
	1. Direct User Interface	2. Immediate Data Availability	3. Security Or Privacy	4. Selective Scene Data
1. Agricultural Surveys	*	*	-	A
2. Emergencies and Natural Disasters	*	*	-	A, S
3. Ocean and Lake Surveillance	0	*	-	S, R, A
4. Other Applications with Volatile Data Value	0	*	-	?
5. Other Applications with Uses for Strong User Interface	* *	0	-	See Note
6. International Applications Tending Toward Small Undeveloped Countries	*, 0	*, 0	*	A, S, R

Legend

Attributes   * Strong need for LCGS capability
             0 Variable or secondary need for LCGS capability

Limitation   A - Data selected for subarea
             S - Spectral channel selection
             R - Degraded resolution selection

Note: These applications may use LCGS to process products from central
       system interactively with user.

SECTION 3

DATA TRANSMISSION TRADEOFFS

3.1 INTRODUCTORY OVERVIEW

Alternate configurations for the data transmission RF link have been
examined to compare the relative complexities, and the costs, of Telemetry
Receiving Stations (TRS) for Local User Terminals. Throughout these inves-
tigations, the following parameters have been held fixed:

- Spacecraft altitude - 735 km.

- Frequency - 8.5 GHz.

- Transmitter power - 10 watts.

- Modulation/detection - FM of carrier by the PCM data bit stream
  with discriminator detection at a bit error rate of 10^{-5}.

Although the selection of transmitter power as 10 W was somewhat arbi-
trary, this value is judged to be a reasonable allocation of spacecraft prime
power (approximately 40 W with a TWT having 25% efficiency) for an auxiliary
transmitter serving Local User Terminals.

FM with discriminator demodulation was selected over other forms (e.g.,
coherent PSK) since the receiver hardware will be simpler and achievable per-
formance is within 2 dB of the optimum coherent PSK, when receiver and
detector implementation losses are taken into account. Coding techniques were
not considered because of their added hardware complexity.

To permit reception of data when the spacecraft subpoint (nadir) is as
far as, say, 1,000 km from the ground station, the ground station antenna must
be autotracked and the spacecraft antenna must be either a program-tracked
beam or have a broad fixed pattern with attendant low gain. Table 3-1 sum-
marizes RF link parameters and performance for a ground station having a
1.3-m-diameter parabolic autotracked antenna and a tunnel diode preamplifier,
with the spacecraft subpoint 1,000 km from the ground station. A fixed space-
craft antenna is assumed, having a broad conical downward-pointing pattern of
about 110° beamwidth. It is presumed that the pattern is shaped (as for the
ERTS wideband data antennas) to provide a gain of 4 dB at 51° from vertical,
the angle from vertical to line-of-sight at 1,000-km offset, in order to partially
offset space attenuation increase as a function of slant range.

Table 3-1

RF Link Budget

Spacecraft Subpoint-to-Ground Station Distance = 1, 000 km	
Transmitter Power (10 watts)	+ 40. 0 dBm
Transmitter-to-Antenna Line Loss	- 0. 5 dB
Spacecraft Antenna Gain (shaped to provide maximum gain 51° from vertical)	+ 4. 0 dB
Space Attenuation (range = 1, 285 km)	-173. 2 dB
Atmospheric and Rain (4 mm/hr) Attenuation	- 0. 5 dB
Receiving Antenna Gain (1. 8 M dish)	+ 41. 5 dB
Polarization Loss	- 0. 5 dB
Received Signal	- 89. 2 dBm
System Noise (system noise temperature = 708°K, bit rate = f_b)	-170. 1 +10 log f_b dB
Required Signal-to-Noise Ratio (12. 5 dB for Pe = 10^{-5} plus 3 dB margin)	+ 15. 5 dBm
Maximum Bit Rate, f_b	3. 4 Mbps

Note: A monopulse type feed is assumed (i. e., no crossover loss as associated with a conical scan feed).

The price of a ground station antenna with monopulse feed, pedestal, autotrack electronics and data receiver meeting the above requirements is in the range of $120, 000 to $150, 000, excluding nonrecurring engineering. Use of conical scanning in lieu of a monopulse feed for tracking would reduce price significantly, and the maximum bit rate would be decreased due to crossover loss by about 1 dB, i. e., to 2. 7 Mbps.

The maximum bit rate may be increased by replacing the tunnel diode preamplifier with an uncooled parametric amplifier. An improvement of about 6 dB, i. e., to 14 Mbps, could be achieved. The Telemetry Receiving Station price would be increased approximately $12, 000. As an alternative, the antenna diameter could be increased to 3. 6 m to obtain a maximum bit rate of 12 Mbps. However, above approximately an 1. 8-m-diameter dish, a significant increase in size of the pedestal and tracking servos would be necessary. Therefore, the uncooled parametric amplifier alternate would be most economical.

For a system with a maximum bit rate requirement of 8 Mbps, the most economical implementation would be a conical scan feed, a 1.8-m dish, and an uncooled parametric amplifier. The price of such a Telemetry Receiving Station would be approximately $90,000 (nonrecurring engineering excluded).

A substantial part of the price of a ground station with antenna autotracking is the autotrack portion. Therefore, its elimination is mandatory to achieve an economical Local User Terminal. This is possible only by increasing the spacecraft antenna gain, either by means of a program-tracked high-gain antenna or a fixed downward pointing beam. The latter configuration does, however, restrict the location of the ground station relative to the spacecraft subpoint track and the duration of the pass over which data may be received (i.e., the ground station must be within the spacecraft antenna beam).

From the above general overview, it is concluded that use of a broad fixed spacecraft beam to permit extensive distance between the spacecraft subpoint and the ground station would result in terminal prices excessive for the majority of potential local users. Consequently, investigations in following sections are constrained to system configurations where the spacecraft antenna is a fixed relatively narrow downward pointing beam or a program-tracked beam.

3.2 PARAMETERS, EQUATIONS, AND GEOMETRY

The parameters, equations, and geometry used in the RF link analyses are summarized herein.

- Frequency (f) -   8.5 GHz

- Transmitter Power (P_t) -   10 watts   40.0 dBm

- Transmitter to Antenna Feed Loss (L_f) -   0.5 dB

- Spacecraft and Receiver Antenna Gains ($G_{s/c}$ and G_r) (paraboloid with 55% aperture efficiency, or equivalent) -

$$G = 36.4 + 20 \log D$$

$$G = 44.3 - 20 \log \phi_{deg}$$

$$\phi_{deg} \, D = 2.48$$

where G = gain in dB, D = diameter in meters, and ϕ_{deg} = 3-dB beamwidth in degrees.

- Space Attenuation -

$$\alpha_s = 111.0 + 20 \log R$$

       where α_s = space attenuation in dB
             R = slant range in kilometers.

- Attenuation by Atmosphere and Rain -

       $\alpha_a + \alpha_r$ as given by the curve in Figure 3-1.

- Polarization Loss (circular polarization assumed) - L_p -   0.5 dB
- For Fixed, Pointable Receiving Antenna, Loss Due to
  Pointing Error (L_{pe}) -   0.5 dB

       This loss is assigned a constant value, independent of beam-
width, reflecting a requirement for greater pointing accuracy
(including knowledge of latitude, longitude, and true north), as
beamwidth becomes smaller. The allowable pointing error
(including that due to position and bearing uncertainties), for
0.5-dB antenna gain decrease below the 3-dB point, is approx-
imately 0.04 x beamwidth (3-dB points), e.g., 0.18° for a
4.5° beamwidth.
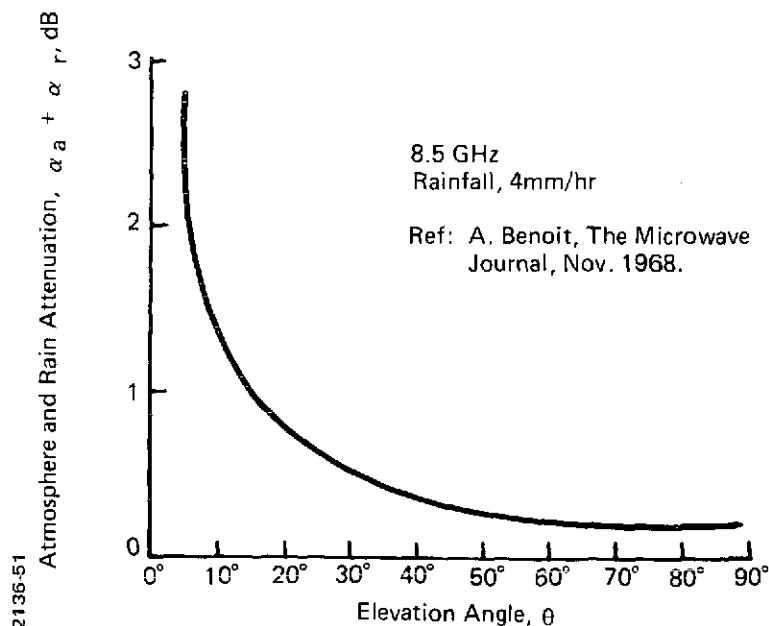
Figure 3-1 Sum of Atmosphere and Rain Attenuation
vs. Receiving Antenna Elevation Angle

- For Autotrack Ground Antenna -

    Conical Scan Crossover Loss (L_s) -   1.0 dB

    Tracking Error Loss at Maximum Azimuth Acceleration (L_t) -

        L_t has been taken as the antenna gain reduction corres-
        ponding to 0.5° tracking error. This is based on: an
        elevation over azimuth pedestal; a distance of 20 km be-
        tween the ground station and the spacecraft subpoint track
        (spacecraft pass 2° from zenith), resulting in a maximum
        azimuth acceleration of 4.6°/sec^2; a system acceleration
        constant of 10 — the resulting tracking error at maximum
        acceleration is 0.46°.

        For a 6-ft dish (1.35° beamwidth), L_t = 1.6 dB;
        for a 3-ft dish (2.7° beamwidth), L_t = 0.4 dB.

- Noise Power Density - $-198.6 + 10 \log T_s = -170.1$ dBm/Hz
                                                            ($T_s = 708°K$)

    where T_s = system noise temperature
          = 708°K with tunnel diode preamplifier (See Appendix A)

- Noise Power - $-170.1 + 10 \log f_b$ dB

        f_b = bit rate, in bits/sec

        (Note — IF bandwidth of receiver is assumed to be
        equal to the transmitted bit rate. See below).

- Required Carrier-to-Noise Ratio — (C/N) Required   15.5 dB

        FM of carrier by PCM bit stream, discriminator demodulation,
        with a bit error probability of 10^{-5}: 12.0 dB C/N required,
        when the IF bandwidth is equal to the bit rate, and $2 \Delta f/f_b$ =
        0.7 where $2\Delta f$ is the peak-to-peak deviation of the carrier.
        Ref. T.T. Tj hung and P.H. Wittke, Carrier Transmission of
        Binary Data in a Restricted Band, IEEE Transactions on Com-
        munication Technology, Volume COM-18, Number 4, August
        1970, pp. 295-304. Add 0.5 dB over theoretical for implemen-
        tation loss, plus 3-dB system margin.

The geometry and associated equations used in the RF link computations
are given in Figure 3-2.

Spacecraft

Υ

R

θ

Ground Station

h

s

R_e

β

$R_e = 6{,}370 \text{ km}$
$h = 735 \text{ km}$
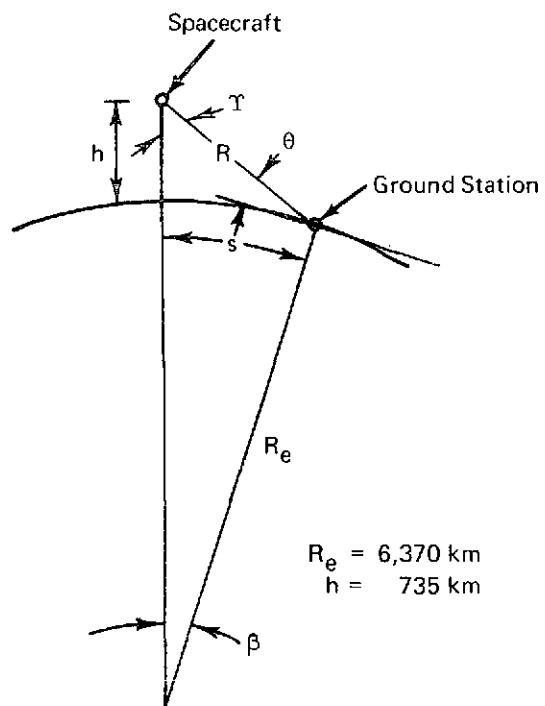
$$\beta = \frac{S}{R_e}$$

$$\beta = \cos^{-1}\left(\frac{R_e}{R_e th}\right) - \theta$$

$$\tan \Upsilon = \frac{R_e \sin \beta}{h + R_e (1 - \cos \beta)}$$

$$\sin \Upsilon = \frac{R_e}{R_e th} \cos \theta$$

$$R = R_e \frac{\sin \beta}{\sin \Upsilon}$$

$$R = (R_e th) \frac{\sin \beta}{\cos \theta}$$

$$\theta + \beta + \Upsilon = 90°$$

Spacecraft Path

h

ϕ

Ground Station

x

R_e

$R_e = 6{,}370 \text{ km}$
$h = 735 \text{ km}$
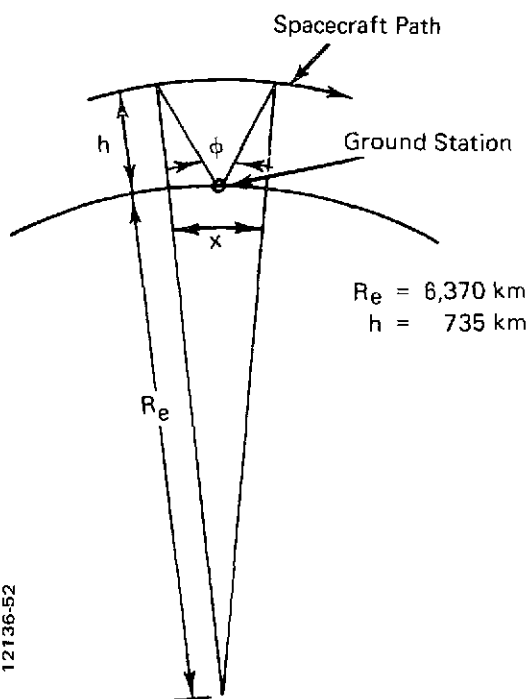
$$\phi = \frac{1}{h}\left(\frac{R_e th}{R_e}\right) X$$

$$\phi \text{ deg} = 0.0869 \, X_{km}$$

12136-52

Figure 3-2 Geometry for RF Link Calculations

3.3 GROUND STATION WITH MANUALLY POINTABLE ANTENNA

3.3.1 Fixed Spacecraft Antenna and Fixed, Pointable Ground Station Antenna

This section investigates system characteristics for a ground station having a pencil beam antenna pattern which may be positioned to establish an RF link while the spacecraft traverses through the beam coincident in time with collection of scanner data from a specified area of the ground. As will be seen from subsequent computations, the spacecraft antenna must be either a program-steered pencil beam or a fixed beam pointing downward, the latter having rather limited coverage. The fixed beam is considered in this subsection and the steered beam in Section 3.3.2.

Figure 3-3 depicts the concept for a fixed spacecraft pattern having a 3-dB beamwidth $\phi_{s/c}$ subtending an area on the surface of the earth having a radius z. The ground station is shown offset by a distance ℓ from the spacecraft subpoint track. This limits the spacecraft traverse to a distance m (m < 2z) over which the ground station is within the spacecraft beam.

The ground station antenna has a 3-dB beamwidth ϕ which is pointed at and subtends a segment x of the spacecraft traverse. A corresponding dimension x along the subpoint track bounds the area from which scanner data are desired. The width of the ground station beam ϕ thus specifies the dimension of the collection area along the subpoint track. The dimension y of the collection area is limited from a fraction up to the complete scanner swath width as determined by the maximum bit rate capability of the system in conjunction with resolution and number of channels of data selected for transmission. Although Figure 3-3 depicts plane earth conditions, computations herein are for a curved earth.

The fixed, pointable receiving antenna configuration is the most economical approach for a ground station having reasonably high bit rate and collection area capability. The expense of autotrack equipment is eliminated and, as will be shown, the beam pointing accuracy requirements are achievable.

The RF link performance is determined from the following equation, where nomenclature is that established in Section 3.2.

$$P_t - L_f + (G_{s/c} - 3\text{ dB}) - \alpha_s - (\alpha_a + \alpha_r) + (G_r - 3\text{ dB})$$
$$- L_p - L_{pe} + 170.1 - 10 \log f_b = (C/N)_{req'd}.$$

Spacecraft

3-dB Antenna
Beamwidth

3-dB
Antenna
Beam-
Width

ϕ S/C

x

ℓ

z

m

Spacecraft
Traverse

ϕ

Area from
Which Data
are Trans-
mitted

Scanner
Swath

x

y

Ground Station

12136-53

Spacecraft
Subpoint Track

ℓ
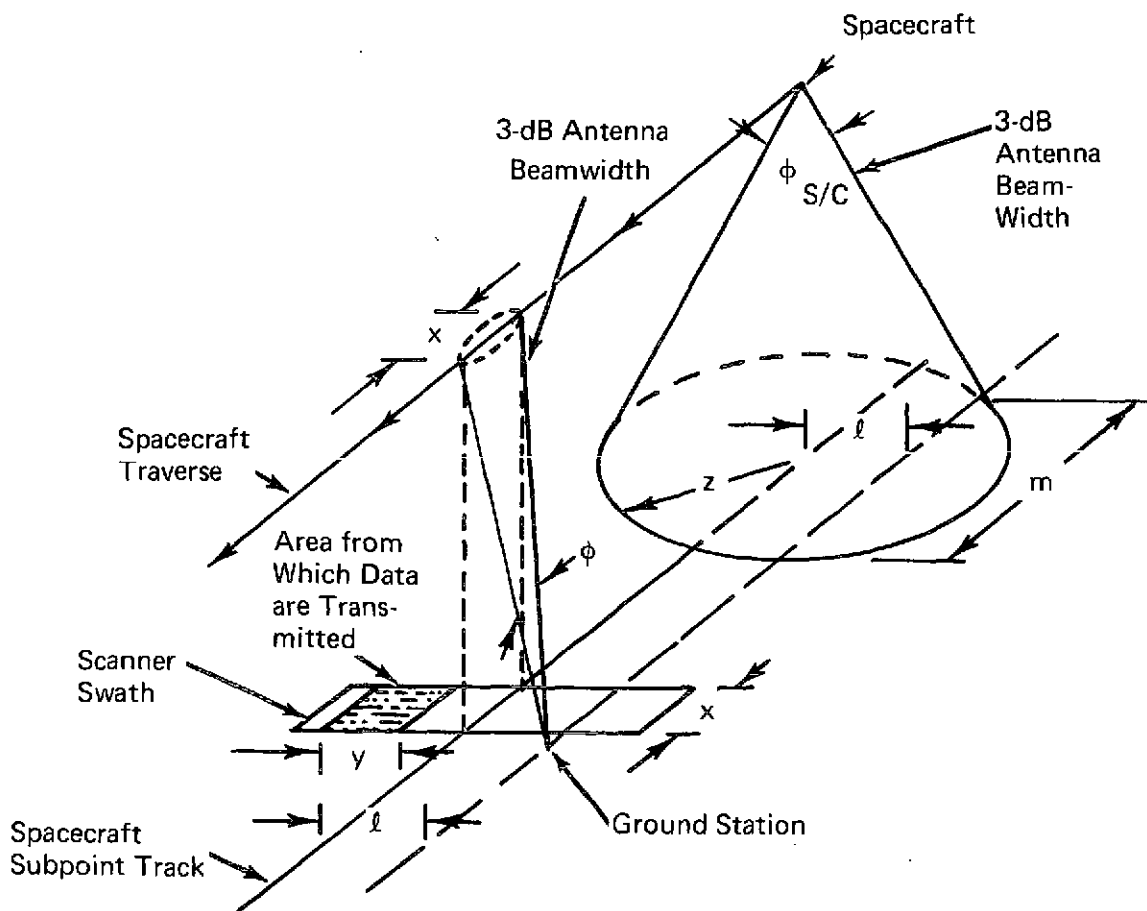
Figure 3-3 Ground Station with Fixed Pointable Antenna
Awaiting Passage of Spacecraft

3-8 (II)

Substituting the parameter values given in Section 3.2, the above equation may be reduced to:

$$G_r - 10 \log f_b + G_{s/c} - 20 \log R - (\alpha_a + \alpha_r) + 76.1 = 0$$

For a selected radius z that the spacecraft antenna beam (3-dB points) subtends on the earth's surface, $G_{s/c}$ is specified by

$$G_{s/c} = 44.3 - 20 \log \phi_{s/c}, \quad (\phi_{s/c} = \text{degrees})$$

where

$$\phi_{s/c} = 2\lambda \text{ and } z = s \text{ in Figure 3-2.}$$

The selected value of z also determines slant range R and elevation angle θ(see Figure 3-2) and $(\alpha_a + \alpha_r)$ is then specified by Figure 3-1. Then the above equation reduces to variables G_r and f_b.

The value of G_r is a function of the dimension x on the earth's surface over which scanner data may be collected (see Figure 3-2.)

$$G_r = 44.3 - 20 \log \phi_{deg}$$

$$\phi_{deg} = 0.0869 \, x_{km} \quad \text{(overhead condition)}$$

For a given value of z_{km} the receiving antenna beamwidth, ϕ_{deg}, and the maximum bit rate capability of the link, f_b, are then specified functions of x_{km}. Figure 3-4 is a plot of f_b and ϕ_{deg} for three different values of z_{km}. (The subscripts km and deg specify dimensions in kilometers and degrees, respectively.) The significances of the three values selected for z_{km} are depicted in Figure 3-5. For z_{km} = 115 km, a ground station situated mid-way between two adjacent subpoint tracks is within the spacecraft beam for a traverse of 162.6 km on two adjacent passes. For z_{km} = 230 km, a ground station situated near a subpoint track is within the spacecraft beam for a traverse of 325.2 km on three adjacent passes. For z_{km} = 460 km, a ground station situated near a subpoint track is within the spacecraft beam for a traverse of 650.4 km on four adjacent passes.

Although the broader coverage of the configurations z_{km} = 230 km or 460 km would be preferred, the allowable bit rate is quite low for reasonably large values of x_{km}. Consequently, the z_{km} = 115 km configuration is the only practical one. Selecting z_{km} = 115 km and f_b = 8 Mbps, one obtains the following system configuration:

Figure 3-4 Receiving Antenna Beamwidth and Maximum Bit Rate vs. the
Dimension X_{km} Fixed Spacecraft Antenna -
Fixed, Pointed Ground Station Antenna

Spacecraft 3-dB Beam
Projection on Ground

162.6 km

Spacecraft 3-dB Beam
Projection on Ground

162.6 km

Spacecraft 3-dB Beam
Projection on Ground

162.6 km

162.6 km

Ground
Station

115 km

Ground
Station

Spacecraft

460 km

Spacecraft

81.3 km

230 km

Ground
Station

Ground
Station

325.2 km

650.4 km

Adjacent Subpoint
Tracks

Adjacent Subpoint
Tracks

Adjacent Subpoint
Tracks

$Z_{km} = 115$ km, $\phi_{S/C} = 17.7°$

$Z_{km} = 230$ km, $\phi_{S/C} = 34.6°$

$Z_{km} = 460$ km, $\phi_{S/C} = 62.8°$

Figure 3-5 Ground Coverage by Three Specified Spacecraft Fixed Antenna Patterns

f_b = 8 Mbps

z_{km} = 115 km

x_{km} = 52 km

Spacecraft Antenna -

$\phi_{s/c}$ = 17.7°

$G_{s/c}$ = 19.3 dB

D = 0.14 m

Ground Station Antenna -

ϕ_{deg} = 4.5°

G_r = 31.2 dB

D = 0.55 m

Requirements for pointing the ground station antenna are exacting but not severe. To suffer no greater than 0.5-dB loss due to pointing errors, the beam must be positioned within ±0.18° of the spacecraft when it is in the desired location (i.e., collecting data over a specified region, x_{km}). This 0.5 dB is an additional antenna gain reduction below the 3-dB point. The ±0.18° must include uncertainties in ground station location and bearing, spacecraft position uncertainties, as well as errors in the antenna mount's pointing mechanism. The pointing error due to an uncertainty in ground station location is:

$$\Delta\theta = \left(\frac{R_e + h}{R_e}\right) \frac{1}{h} \Delta s$$

or

$$\Delta\theta_{deg} = 0.0869 \Delta s_{km}$$

where Δs_{km} is the uncertainty in location of the station. The above equation is for the worst-case condition, spacecraft overhead. For a position uncertainty Δs_{km} = 1 km, $\Delta\theta_{deg} \approx 0.09°$. This position uncertainty is approximately 30 sec of arc in latitude and longitude at the equator. Location may be established to this accuracy at many locations within the United States by use of a US Geological Survey Map. If required, both latitude and longitude may be determined to 15 sec of arc or better by star sighting with an engineer's transit. An accurate chronometer, referenced to a precise time

standard, must be carried to provide a local time to 1 sec in order to determine longitude. From the above, it is concluded that a reasonable allotment for antenna pointing error due to station location uncertainty is 0.09°. It is presumed that uncertainty in spacecraft location is negligible compared to the above uncertainty in ground station location. A true north-south line may be established at the site by observation of Polaris at elongation with an engineer's transit. The error should not exceed 10 sec of arc when reasonable care is taken in making the determination. Local vertical may be established to 20 sec of arc or better by means of two orthogonal tubular type bubble levels. A suitable mount will require provisions for precise leveling, a telescope on the mount for establishing azimuth reference by sighting on a staked north-south line and axes orthogonal to about 20 sec, each having a scale and vernier to permit position readout at intervals of 0.05° or better. In addition, an initial boresight measurement must be made to establish the antenna pattern center relative to the verniers. Determination of the mean position of points on the antenna pattern near the 3-dB points to 0.1 dB will reduce boresight error to about 0.04°.

A reasonable allocation for total antenna pointing error is thus:

Station location uncertainty	0.090°
Leveling error (30 sec)	0.008°
Azimuth reference error (20 sec)	0.006°
Non-orthogonality of axes (30 sec)	0.008°
Mount readout error	0.025°
Antenna boresight error	0.040°
Total pointing error	0.177°

3.3.2 Program-Tracked Spacecraft Antenna with Fixed, Pointable Ground Station Antenna

System performance (either in bit rate capability or increase in the dimension x_{km} along the spacecraft track over which data may be collected) may be improved substantially by using a program-tracked spacecraft antenna. Selecting an antenna having 30-dB gain (5.1° beamwidth, 0.49-m dish or equivalent) and assuming operation out to 500 km between the ground station and spacecraft subpoint, the performance depicted in Figure 3-6 may be achieved. Note that for a data rate of 8 Mbps the dimension x_{km} = 182 km and the receiving antenna beamwidth is about 16°. Or, as an alternative, for a data rate of 33 Mbps, x_{km} = 90 km (minimum, spacecraft overhead) and ϕ_{deg} = 7.9°. In addition to substantially improved system performance, the positioning requirements imposed on the receiving antenna may be relaxed.
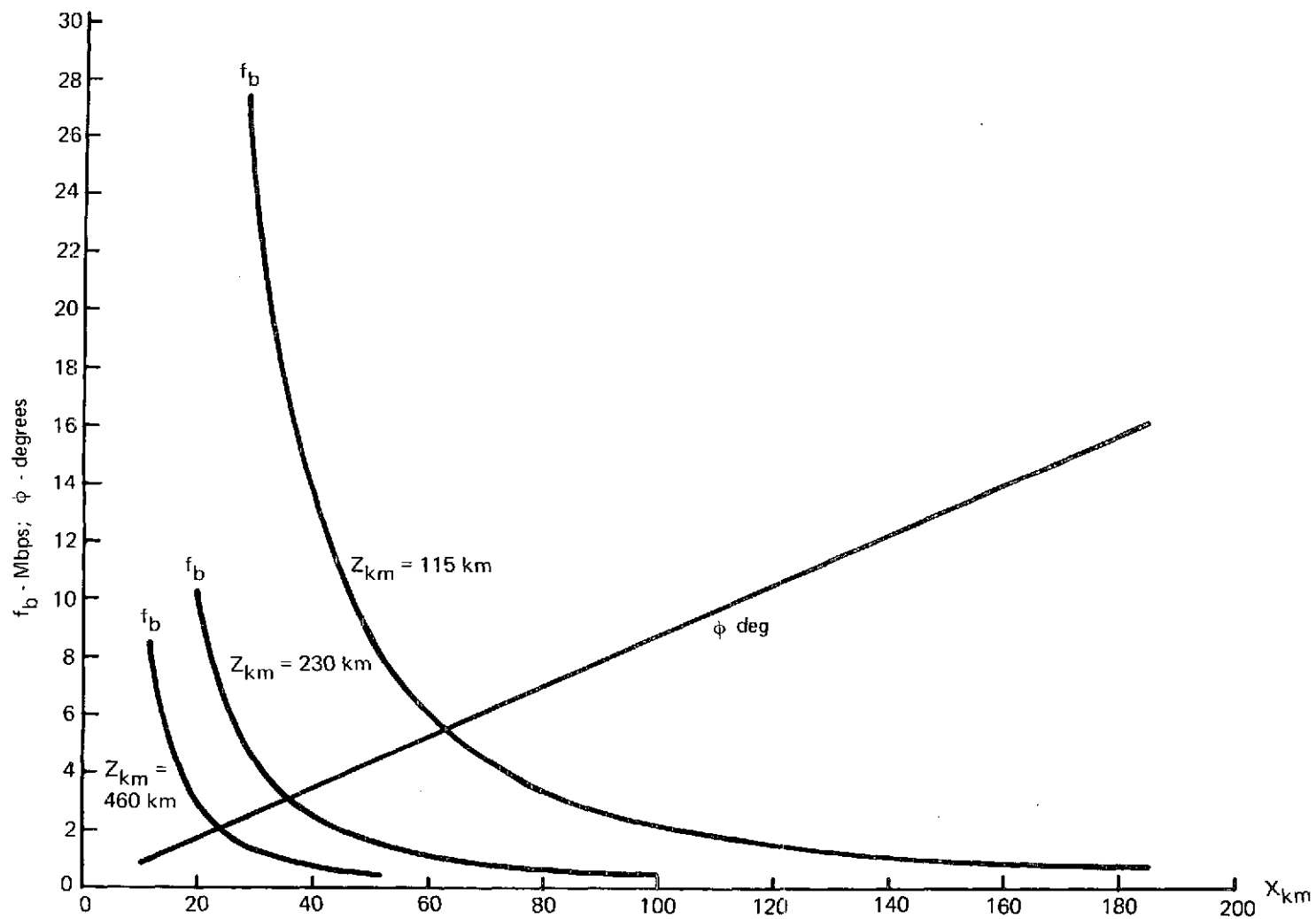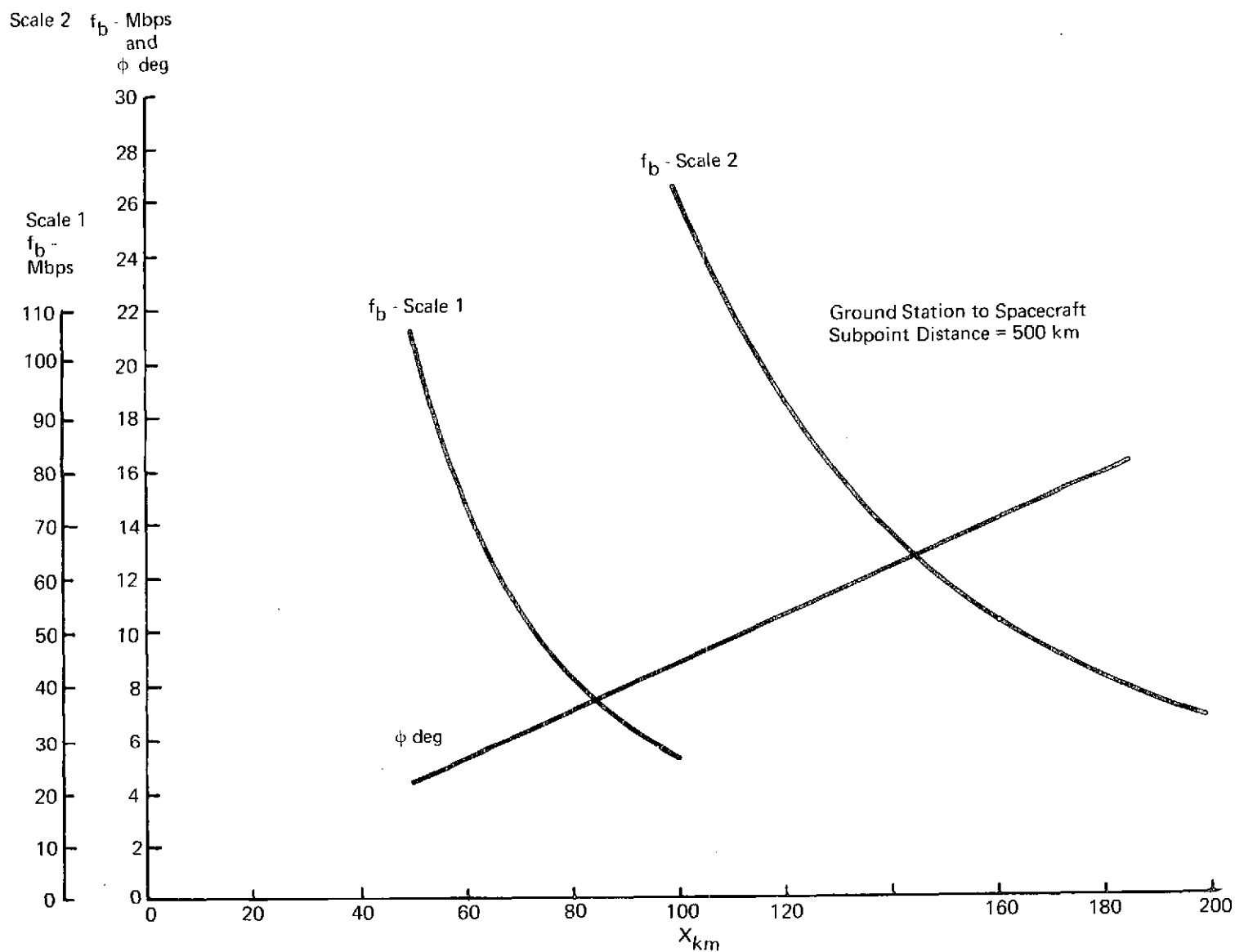
Figure 3-6   Receiving Antenna Beamwidth and Maximum Bit Rate vs. the
Dimension X_{km} Program - Tracked Spacecraft Antenna -
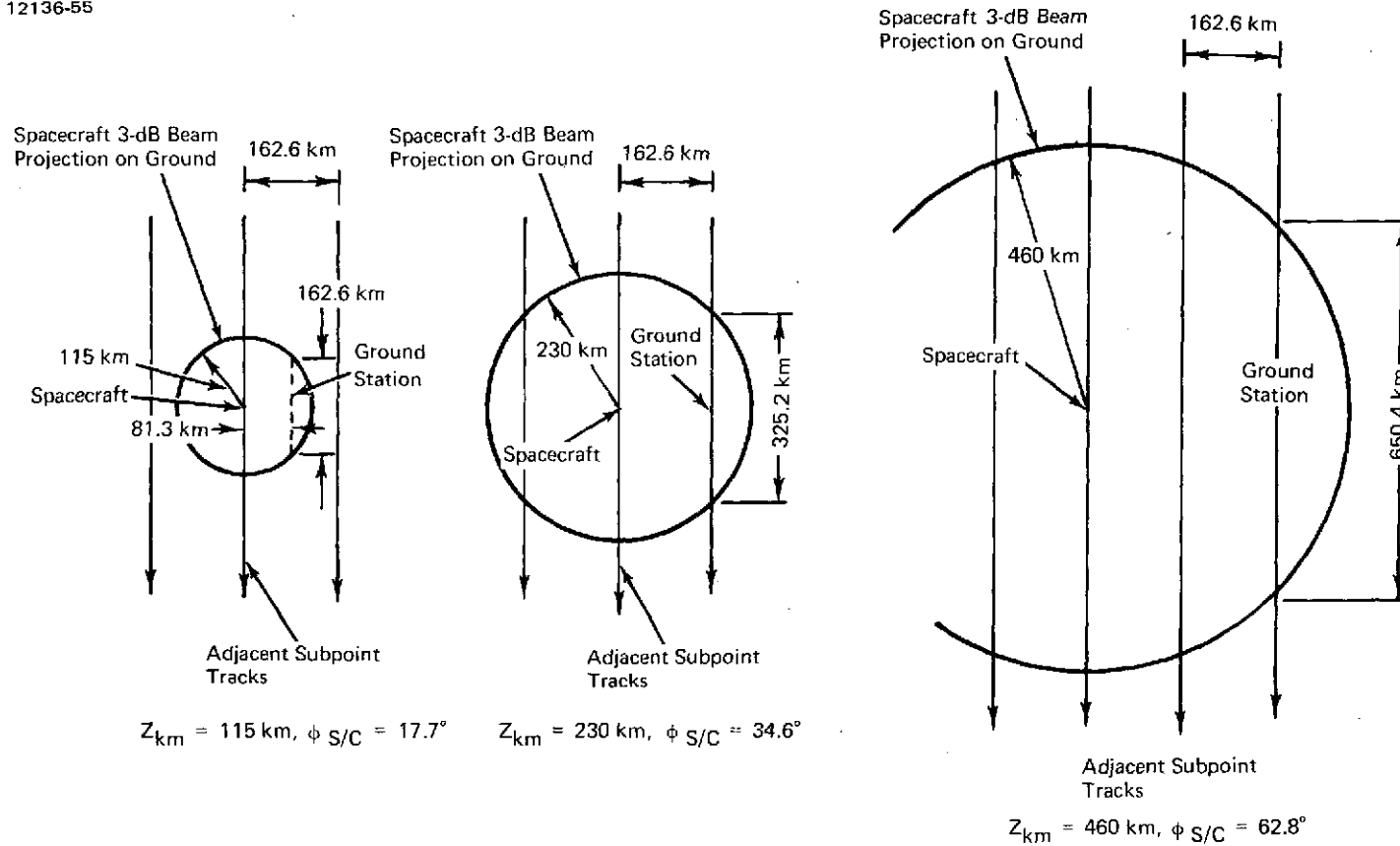Fixed, Pointed Ground Station Antenna

3.3.3 Manually Tracked Ground Station Antenna

Returning to the case of a fixed spacecraft antenna subtending a radius $z_{km} = 115$ km on the ground and a 4.5° receiving antenna beamwidth, the dimension along the spacecraft track over which data are collectable may be increased from $y_{km} = 52$ km to 163 km (see Figure 3-5), if the receiving antenna can be either manually or program tracked. For this restricted condition, the spacecraft remains nearly in a plane passing through the ground station site, thereby allowing track in one axis only. The angular rate of motion in this plane relative to the ground station is about 0.7°/sec. Although this rate is nearly constant for the short spacecraft traverse of interest, it will vary with latitude due both to the earth's rotation and spacecraft velocity changes. Consequently, a simple fixed rate program-tracked antenna is not possible with a 4.5° beamwidth. However, manual tracking using signal strength for an indication appears to be practical. The antenna would be positioned initially so that it points at the spacecraft when its beam (3-dB point) just passes over the ground station. The initial reaction time for an operator to pick up the track and maintain position within the receiving antenna 3-dB points is about 6 sec. It is believed that this amount of time for acquisition and the 0.7°/sec rate are values which will permit an operator to track successfully. However, before committing to a manual track system, it is recommended that an experimental investigation be performed to assure that most operators could perform this task after brief simulated training.

A three-axis mount would be required, one around which the antenna is tracked during spacecraft passage and two more to initially position the first axis perpendicular to a plane which passes through the ground station site and the spacecraft traverse line. Each axis would have to be orthogonal to about 10 sec of arc and positioning of each axis to about ±0.01° would be required. The axis about which the antenna is tracked would require remote positioning by means of a servo control, as it is judged that direct manual slewing while watching a signal strength indicator would not be feasible.

A mount of this type may very well be as costly as a two-axis auto-track system, even though servo drive in one axis is eliminated and a conical scan or monopulse type feed for the antenna is not required. Since no existing mounts meeting or approaching the above requirements could be found, it has not been possible to adequately assess feasibility and cost effectiveness of this manual track approach.

3.3.4 Implementation and Estimate of Price

Figure 3-7 is a block diagram depicting implementation of a Telemetry Receiving Station suitable for meeting the requirements of Section 3.3.1 for a fixed, pointable receiving antenna. This is for the fixed spacecraft antenna whose beam subtends a 115-km radius. The principal parameters for the equipment are listed in the figure.

All of the components, except for the antenna mount, are available on special order from several companies specializing in that component. Although none are strictly "off-the-shelf," minimal engineering is required to apply existing designs and hardware technology. The price information on the components listed below is based upon quotes from competent suppliers. These quotes were sufficiently close to assure credibility of the numbers given below. Two quotes were obtained for the antenna dish and feed, three for the preamplifier/down converter package, two for the IF amplifier/limiter/discriminator, and one for the bit synchronizer. The prices for system integration and acceptance testing are estimates by Bendix, solely, and are considered representative of the prices to be expected from any competent RF system integrator. The nonrecurring engineering includes preparation of component specifications, technical monitoring of suppliers during procurement, special noncapital type equipment for integration and acceptance test, test procedures, and a user operation and maintenance manual.

An extensive, but not exhaustive, search of literature and telecons was made in an attempt to locate an antenna mount meeting, or nearly meeting, the requirements. Unfortunately, none could be found. Several companies make small pedestals for autotracked antennas which provide precise pick-off and readout of angular positions. These could be used and would provide the convenience of remote manual positioning; however, the price is excessive, approximately $12,000. One antenna company markets a sturdy tripod-mounted, manually positioned elevation/azimuth scales. However, angular accuracy is no better than 1° and leveling is no better than 10 minutes of arc. One manufacturer of camera mounts markets an elevation-over-azimuth pan head with scale and vernier readout to 15 minutes of arc. However, this company was not able to identify either the orthogonality of the axes, the parallelism of the mounting plate to the elevation tilt axis, or the accuracy of scale and vernier marking.

One possible low-cost solution warranting further investigation is the mounting of a machine shop type vertical rotary table atop a horizontal rotary table to provide two accurately positionable orthogonal axes. These are

Antenna Dish and Feed

Beamwidth = 4.5°
Gain ≈ 31 dB
Dia ≈ 0.55 m
Circularly Polarized
Horn Feed
Weight ≈ 5.4 kg

Temperature Controlled Preamp and Downconverter
Package, Mounted on Antenna Mount

Weight ≈ 3.6 kg
Volume ≈ 5250 cm³

Hard Limiting at 0 dBm Input
Discriminator Linear
Range ± 3 MHz

PCM
Data

| Tunnel Diode Preamplifier | Image Rejection Notch Filter | Double Balanced Mixer | IF Preamplifier 70 MHz | | IF Amplifier 70 MHz | Limiter/ Discriminator and Video Amplifier | Bit Synchronizer 8 Mbps |

Data
Clock

Noise Figure 4.6 dB
Gain 17 dB

Rejection
> 20 dB

Noise Figure 1.5 dB
Gain 15 dB
Bandwidth 15 MHz

Conversion Loss 7.5 dB

Local
Oscillator

Mounting Panel for:
Signal Strength Meter
IF Amplifier and Limiter/
Discriminator
Power Distribution

Minimum Received
Signal -86 dBm

Frequency Modulation
at 8 Mbps, 5.6 MHz
Peak-to-Peak Deviation

Elevation
Over
Azimuth
Mount

Stability
1 pt in 10⁵

3-dB Bandwidth 8 MHz
Gain 70 dB

Either AGC or Log IF
to Provide Signal Strength
Indication

Leveling to ± 20 sec
Axes Orthogonality ± 20 sec
Position Repeatability and
Readout to ± 0.025°
Antenna and Telescope
Boresighted to ± 0.04°
Weight ≈ 55 kg

Figure 3-7   Telemetry Receiving Station with Fixed, Pointable Antenna

rugged precision components with angular readout to 1 minute of arc or better throughout 360°. However, weight is excessive, 58 kg for a 0.3-m-diameter table, i. e., total weight of 116 kg. One manufacturer has agreed to investigate whether a significant weight reduction could be achieved while still maintaining position accuracy with a much lighter 9-km load of antenna and preamplifier/down converter than the rather high loads these tables are designed to accept.

A quote was obtained for a specially designed mount to meet our requirements. The company who provided this quote is engaged in design and manufacture of astronomical instrument mounts of precision well in excess of our requirements. The quoted pedestal design would use their existing technology and some existing hardware designs. It is believed that this company understood the requirements well and that the quote represents a good estimate. Therefore, it is used in the following system price estimates:

First unit, including nonrecurring engineering	$85,000
1 each, additional units	$31,000

Prices for the first unit absorb all nonrecurring engineering. The price of subsequent units is based on procurement one at a time. It is estimated that this per-unit price could be reduced by about 20% if concurrent procurement in a quantity of 10 was made. All prices are based on 1973 economic conditions.

If the spacecraft antenna is program tracked and the ground station configured for an 8-Mbps maximum data rate, the ground station antenna beamwidth may be increased to 16° (see Section 3.3.2). This would permit a pointing error of ±0.64° for 0.5-dB additional loss below the 3-dB points. Relaxation of pedestal requirements for this case should reduce per-unit system price by about $3,000.

No estimates are available for the price of a pedestal for manually tracking of the ground station antenna as described in Section 3.3.3. It is feared that the price would run as high as for an autotrack pedestal and controller including the additional price for a conical scan feed. This, however, deserves further investigation.

3.4 GROUND STATION WITH AUTOTRACK ANTENNA

3.4.1 System Requirements and Performance with Fixed Spacecraft Antenna

A ground station having a fixed, pointable antenna as described in Section 3.3 is considered to be the primary terminal for local users. Consequently, unless a program-tracked spacecraft antenna is provided, the system is presumed to be configured with a spacecraft antenna having 19.3-dB gain, 17.7° beamwidth, and subtending a radius of 115 km on the ground. Certain users, however, may require the greater along-track coverage and/ or higher bit rate which may be achieved with an autotracked antenna. This section identifies the parameters and performance of such a terminal for the case of the fixed (19.3 dB) spacecraft antenna.

The RF link performance is defined by the following equation where the nomenclature is as specified in Section 3.2:

$$P_t - L_f + (G_{s/c} - 3 \text{ dB}) - \alpha_s - (\alpha_a + \alpha_r) + G_r$$

$$- L_s - L_t - L_p + 170.1 - 10 \log f_b = (C/N)_{req'd}$$

Substituting the parameter values given in Section 3.2, $G_{s/c} = 19.3$ dB and α_s and $(\alpha_a + \alpha_r)$ corresponding to $s = 115$ km, the above equation reduces to:

$$G_r - L_t - 10 \log f_b + 40.2 = 0$$

The loss parameter L_t is the tracking loss of an elevation over azimuth pedestal for a near overhead pass, and is taken to be that loss which corresponds to 0.5° tracking error as described in Section 3.2. Figure 3-8 may be used to determine the value of L_t for a given antenna beamwidth. (The use of α_s and $\alpha_a + \alpha_r$ at maximum range and L_t for a near overhead pass results in somewhat greater than actual losses for narrow beamwidths.) L_t would be negligible for an x-y pedestal. Using the above equation plus

$$G_r = 44.3 - 20 \log \phi_{deg} \quad \text{and} \quad D = \frac{2.48}{\phi_{deg}} \text{ meters,}$$

antenna diameter and beamwidth are plotted as a function of bit rate f_b in Figure 3-9.
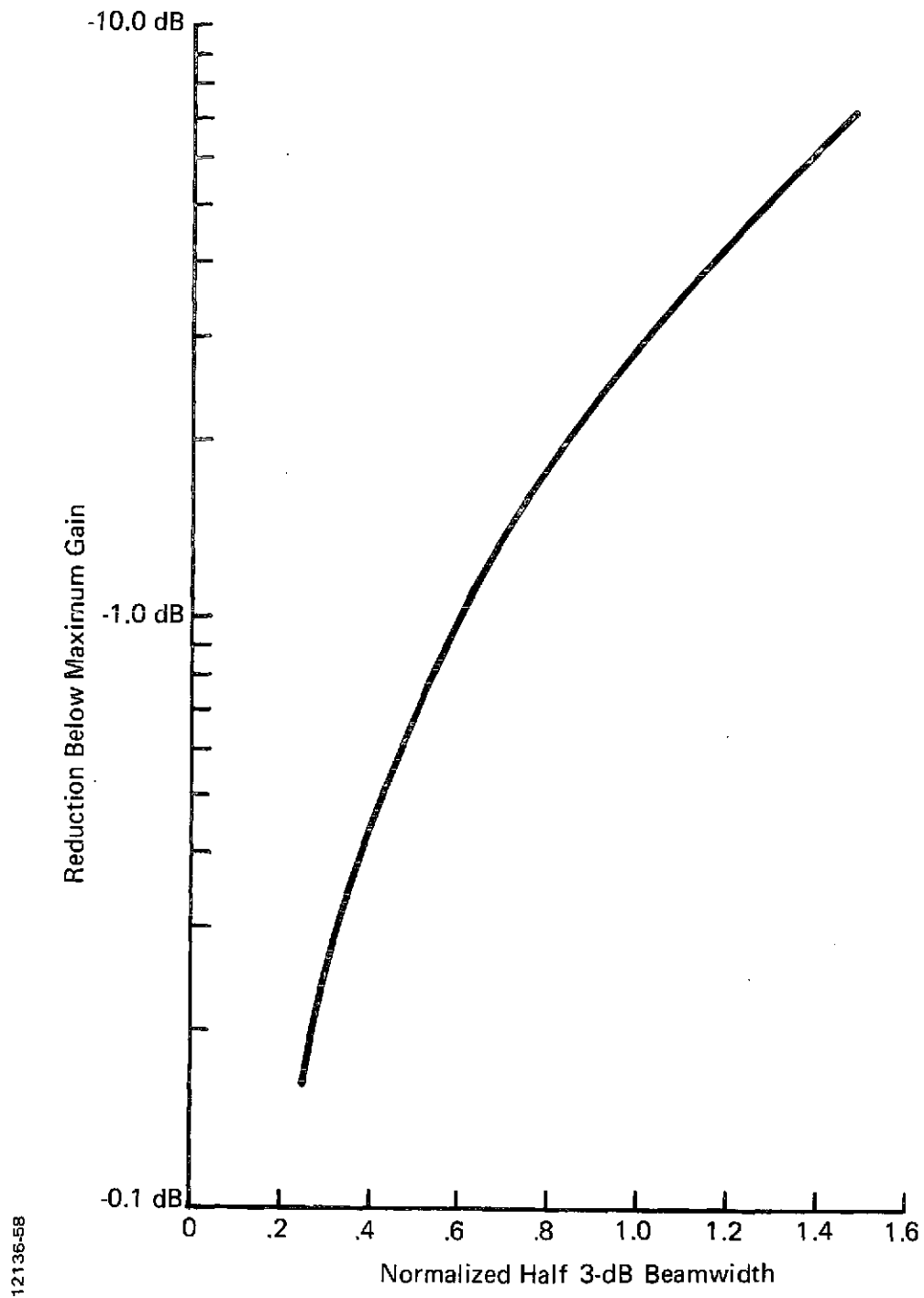
Figure 3-8 Reduction in Maximum (Boresight) Antenna Gain vs.
Normalized Half 3-dB Bandwidth
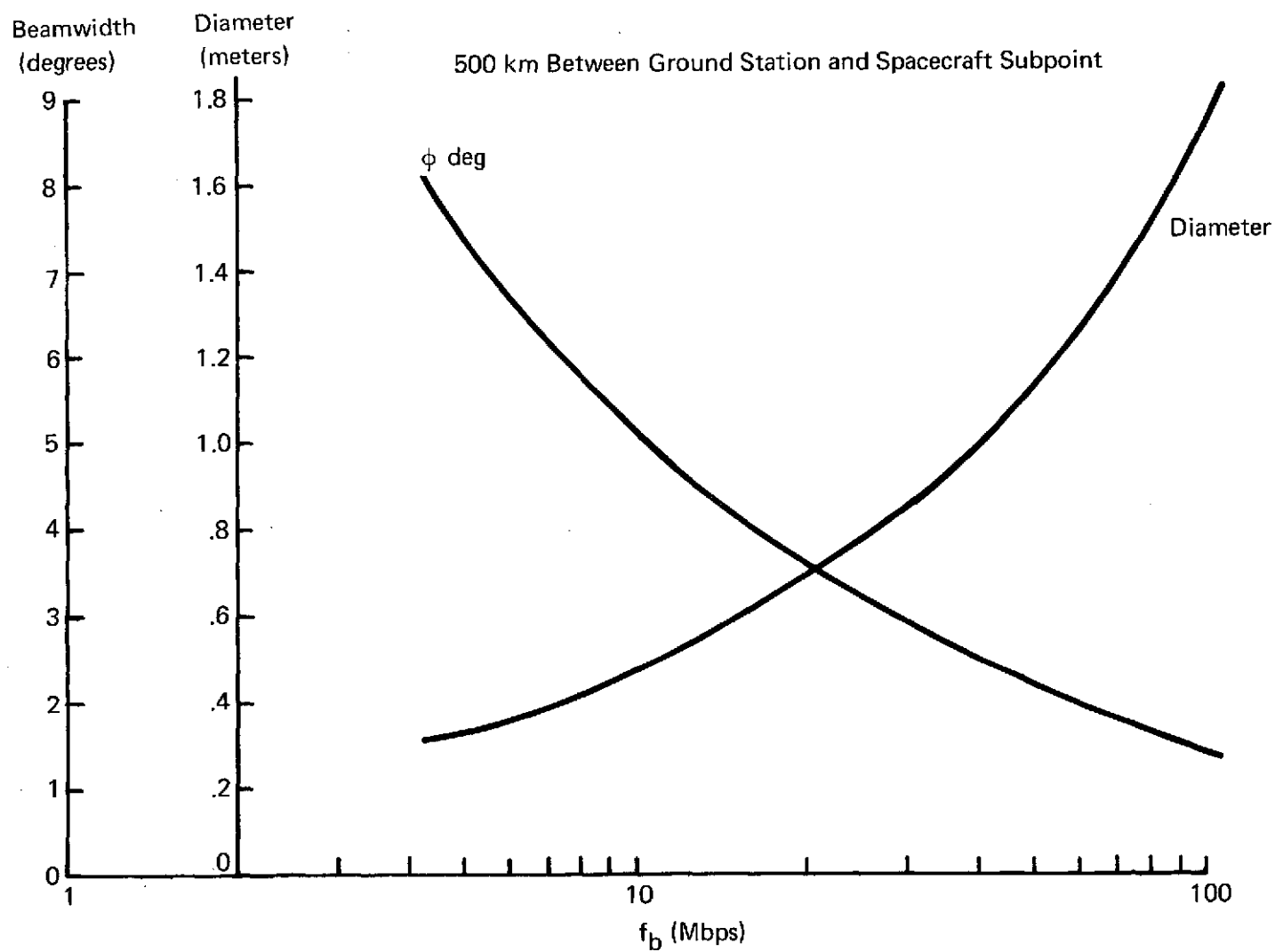
Figure 3-9 Receiving Antenna Beamwidth and Diameter vs. Bit Rate for Fixed
Spacecraft Antenna with $G_{S/C}$ = 19.3 dB (Subtends 115-km Radius)

Three discrete points on Figure 3-9 are of particular interest:

f_b = 8 Mbps f_b = 33 Mbps f_b = 106 Mbps

ϕ_{deg} = 5.8° ϕ_{deg} = 2.7° ϕ_{deg} = 1.3°

Dia = 0.4 m   Dia = 0.9 m   Dia = 1.8 m

From both price and mobility standpoints, there would be little advantage to restricting dish size to 0.4 m even if the overall system capability were limited to 8 Mbps by recording and data processing constraints. A dish diameter of 1 to 1.2 m would provide added link margin over the 3 dB used in the calculations up to and including a bit rate of 33 Mbps, and at nearly the same price.

An increase in dish diameter up to 1.8 m would increase price somewhat, but not substantially, as most existing autotrack pedestal designs capable of accepting a 1-m dish may also accommodate up to a 2-m dish. Two meters is about the size at which one must switch to a substantially more costly pedestal. This statement is with reference to use of existing pedestals as opposed to a new pedestal design sized to one specific dish size. The use of a dish as large as 2 m for data rates of 8 or 33 Mbps might, however, reduce the ease of dish storage and mobility of a mobile station compared to, say, a 1.2-m dish.

Note that, even with the system bit rate limited to 8 Mbps due to recording and data processing constraints, the autotracked antenna has an advantage. It would permit collection of data over a substantially larger along-track dimension, 163 km (see Figure 3-5), as opposed to 52 km for the fixed, pointable antenna (see Section 3.3.1).

3.4.2 System Requirements and Performance for Program-Tracked Spacecraft Antenna

The combination of a program-tracked spacecraft antenna and an autotracked receiving antenna provides the significant advantage of wide area coverage over other system configurations wherein coverage is restricted by either or both the spacecraft and receiving antenna beam.

Figure 3-10 is a plot of receiving antenna beamwidth and diameter requirements for a spacecraft antenna gain of 30 dB and assumes desired coverage out to a distance of 1,850 km between the ground station and the spacecraft subpoint. Note that the maximum bit rate of 106 Mbps may be accommodated with a 1.2-m-diameter dish. It would be advantageous to use a
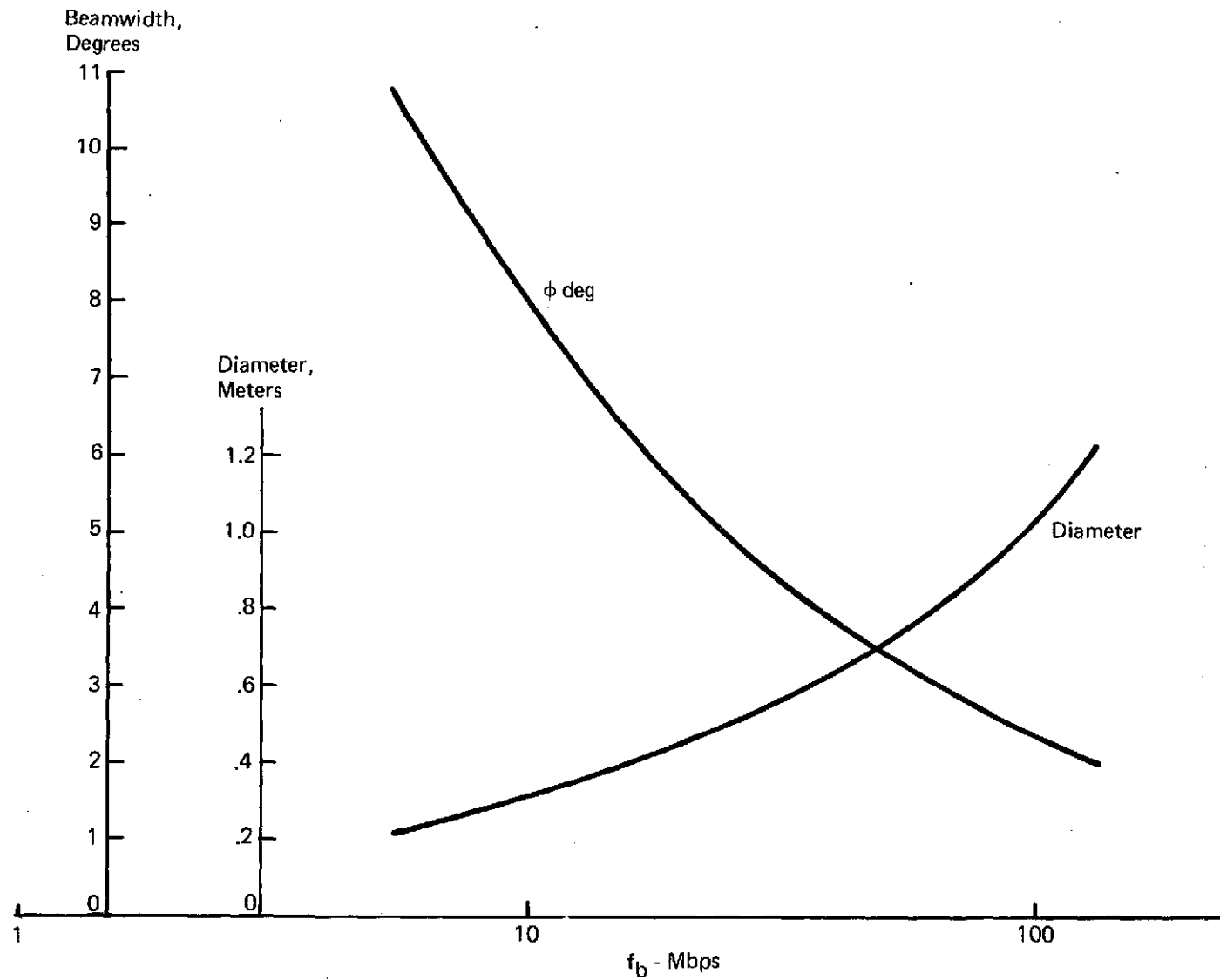
Figure 3-10 Receiving Antenna Beamwidth and Diameter vs. Bit Rate for Program Tracked Spacecraft Antenna with $G_{S/C}$ = 30 dB

1.2-m dish for all terminals even though the bit rate capability were constrained by recording or data processing equipment. This would permit later upgrading of the terminal to a higher bit rate without any changes to the RF portion. The additional price for the larger dish would not be great and station mobility would not be impaired.

3.4.3 Implementation and Estimate of Price

A typical price range for a Telemetry Receiving Station employing an autotracked antenna and having a receiver capable of up to about 20 Mbps is $120,000 to $150,000, excluding nonrecurring engineering. This is for up to a 2-m dish, an azimuth over elevation pedestal, and autotracking by means of a pseudo-monopulse antenna feed and error signal generation. The use of conical scanning for autotrack would simplify the feed and the generation of error signals. Furthermore, an x-y (traverse over elevation) pedestal would decrease the dynamic requirements for near-overhead passes and therefore could reduce price. Although an x-y pedestal would have regions of high angular acceleration for near-horizon spacecraft conditions if the pedestal horizontal axis were perpendicular to the subpoint track, these regions may be avoided entirely by placing the horizontal axis roughly parallel to the subpoint track.

Figure 3-11 is a block diagram of a Telemetry Tracking Station based on the use of an x-y pedestal and a 1.2-m dish. The principal component parameters are given in the figure. Note that a bit rate of 8 Mbps is specified.

One company which specializes in autotracking microwave antenna and receiving systems, including pedestals, has developed a small x-y (traverse over elevation) pedestal which would be specifically applicable. This pedestal is capable of supporting up to a 2-m dish, has maximum velocity and acceleration capabilities of $4°/\text{sec}$ and $4°/\text{sec}^2$, respectively, weighs 75 kg, and is slightly greater than 1 m high from the mounting base up to the traverse axis. This company also specializes in conical scan feeds, as well as monopulse. Based upon a budgetary quote from this company for the system depicted in Figure 3-11, exclusive of the IF portion and bit synchronizer, the following price estimates for the entire system are judged to be reliable:

First unit, including nonrecurring engineering	$120,000
1 each, additional units	$ 72,000

The price of terminals ordered concurrently in quantities of 10 each would be 15% to 20% lower per unit.

Antenna Dish and Feed

Dia ≈ 1.2 Meters
Gain ≈ 37 dB
Circularly Polarized
Conical Scan Feed
Weight 45 kg

Temperature Controlled Preamp and Downconverter
Package, Mounted on Pedestal

Weight ≈ 3.6 kg
Volume ≈ 5250 cm^3

Hard Limiting at 0 dBm Input
Discriminator Linear
Range ± 3 MHz

Minimum Received
Signal - 78 dBm (Fixed S/C Ant)

Frequency Modulation
at 8 Mbps, 5.6 MHz
Peak-to-Peak Deviation

X-Y
Pedestal

Tunnel
Diode
Preamplifier

Image
Rejection
Notch
Filter

Double
Balanced
Mixer

IF
Preamplifier
70 MHz

IF
Amplifier
70 MHz

Limiter/
Discriminator
and Video
Amplifier

Bit
Synchronizer
8 Mbps

PCM
Data

Data
Clock

Noise Figure 4.6 dB
Gain 17 dB

Rejection
> 20 dB

Noise Figure 1.5 dB
Gain 15 dB
Bandwidth 15 MHz

Conversion Loss 7.5 dB

Local
Oscillator

Stability
1 pt in 10^5

Mounting Panel for -
Signal Strength Meter
IF Amplifier and
Limiter/Discriminator
Power Distribution

Vel, Each Axis 4°/Sec
Accel, Each Axis 4°/Sec^2
Travel, Each Axis ± 90°
Data Outputs 1X and 36X
Synchros
Backlash 0.1°
Orthogonality 0.02°
Weight ≈ 75 kg

AM Demodulated Pointing Error Signal

Antenna
Controller

Modes:

Manual
Search
Autoacquisition
Auto

Figure 3-11   Telemetry Receiving Station with Autotracked Antenna

The configuration of the terminal for 33 Mbps would require a higher IF frequency, say to 160 MHz, to obtain the required 33-MHz bandwidth. Hardware designs exist and the price increase is insignificant. The bit synchronizer applicable at 8 MHz is the one developed for ERTS, but with a different plug-in. However, it may be extended only up to about 21 MHz. Another company does have a unit capable of operating up to 75 MHz; however, a price estimate was not obtained.

No effort was expended in attempting to estimate additional terminal price if configured for 106 Mbps. The IF, demodulator and bit synchronizer would change. It is likely that the equipment developed for the regional EOS terminals would be employed in Local User Terminals.

SECTION 4

SPACECRAFT DATA PROCESSING TRADEOFFS

This section includes discussions relative to the data processing functions that must be performed within the spacecraft system so that a data stream can be generated for transmission to the low-cost ground station. The data processor is envisioned as an "add-on" piece of hardware that parallels the processing functions performed within the Multimegabit Operation Multiplexer System (MOMS). Operationally, it is totally independent of the normal mode of operation in which the MSS data are collected and formatted by the MOMS. It is possible for thermal data to be collected, formatted, and transmitted to the LCGS without the MOMS being operative. This feature provides the capability to operate at night in a power conserving mode.

Requirements and constraints unique to the spacecraft data processor are presented along with various sets of tradeoff information.

4.1 REQUIREMENTS AND CONSTRAINTS

In addition to the requirements given in Section 1, there are various requirements and constraints which directly affect the spacecraft data processor. The primary interfaces between this processor and other spacecraft systems can be seen in Figure 4-1. The more important additional requirements are given below:

1. Small local user ground stations must be able to operate independently of Goddard except for the requesting and the scheduling of "data dumps." The transmitted bit stream therefore will include any special data that are necessary for adequate data reduction, such as calibration data. GSFC will schedule the requested data collection periods and subsequent data dumps and provide the station with any special information required to make the data transmission meaningful.

2. The basic data as output from the MOMS are transmitted directly with no buffering within the spacecraft for data smoothing purposes. Therefore, any buffering which may be required for operation with the small local user stations must be provided within the LCGS spacecraft data processor.

3. Transmission of wideband data will normally occur concurrently with transmission of narrowband data to an LCGS.
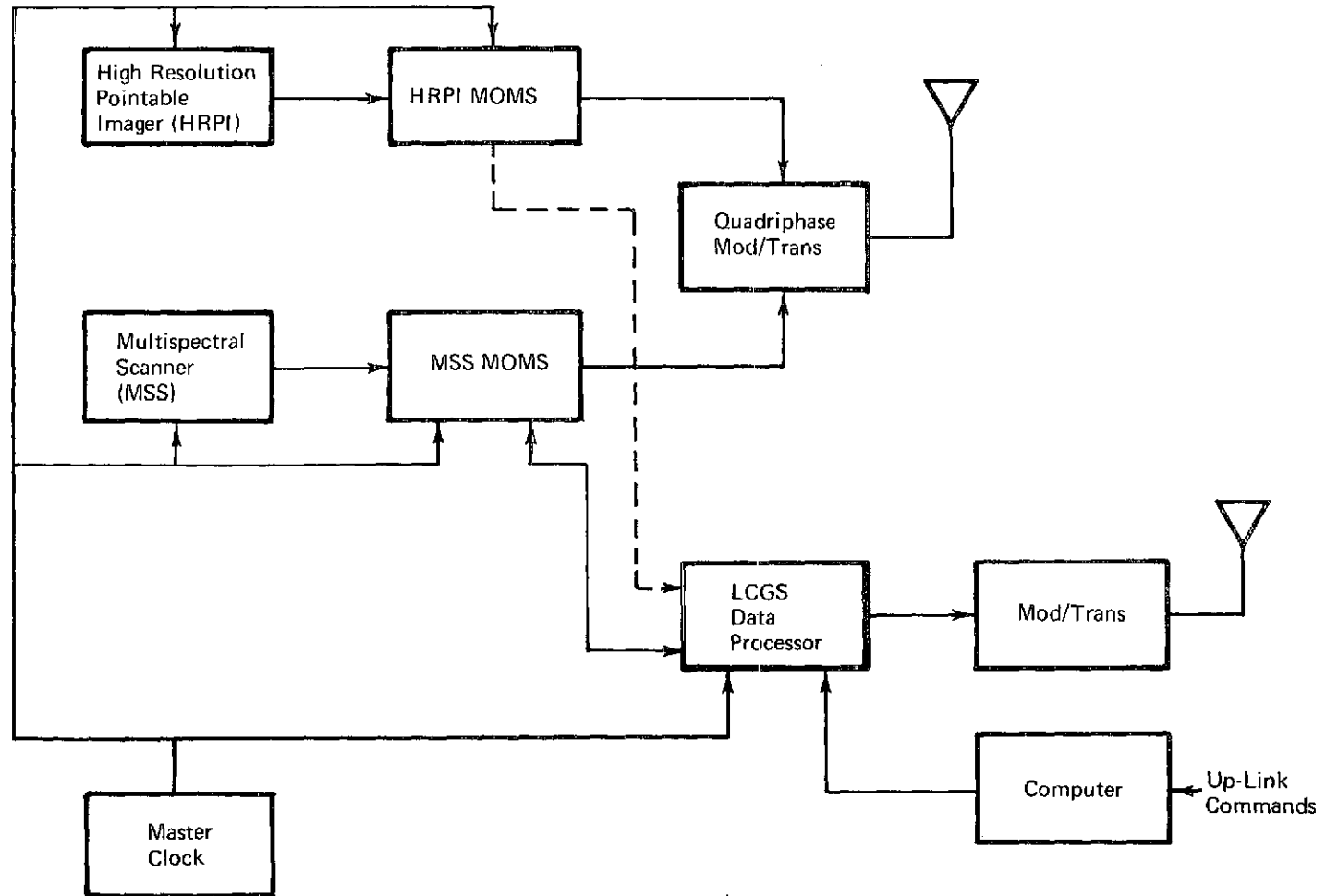
Figure 4-1 Interface Diagram of EOS LCGS Data Processor

4. As a first approximation, the spacecraft data handling functions, required for operation with the small local user station, are independent of the type of scanner instrument being utilized; i.e., the overall complexity of the data handling function is approximately the same for both cases.

5. The spacecraft roll rate is so low that it can be assumed to be zero. Furthermore, the total roll angle will be on the order of one resolution element.

6. Functions which could easily be performed on either side of the MOMS/scanner interface will be performed within MOMS to minimize the electronics required within the scanner instrument, e.g., analog-to-digital conversion and sampling control.

7. The MOMS will be uniquely designed to meet the EOS mission requirements and therefore will be configured to include functions that are uniquely required for a specific scanner system.

8. The detailed specification of MOMS and the LCGS data processor hardware will be compatible with both the scanner(s) and the data link. That is, the quantity of cells/scan, duty cycle, transmission rate, and memory word length will be chosen so as to be compatible.

9. Data, which are obtained from the high data rate multispectral scanner (or the high resolution pointable imager) and which are routinely routed through MOMS, are essentially the only data to be transmitted to a small local user station. Other data, e.g., calibration data, which are required for ground processing of the scanner data will also be transmitted. Data normally routed through the VIP or MIRP will not be transmitted to an LCGS.

10. Since the quantity and quality (amount of spatial compression) of the data to be transmitted to the small local user station is likely to change periodically, especially to different stations, the onboard data processing unit will contain certain reprogrammable features and the transmitted bit stream may contain certain mode identification data.

11. All users are interested in receiving the full radiometric resolution; i.e., 6-bit quantization levels will be utilized for both data transmitted in the normal manner and those transmitted to an LCGS.

12. Data shall be available for transmission to an LCGS at full spatial resolution.

13. Data may be transmitted from the satellite at either of two rates, e.g., about 1.2 Mbps during nighttime operation and at either 8 or 33 Mbps.

4.2 POTENTIAL DATA PROCESSOR CONFIGURATIONS

There are many ways in which a data processor, which extracts data for transmission to an LCGS, can be added to the basic system configuration. A functional block diagram of the units to which the data processor interfaces is shown in Figure 4-2. Figures 4-3 through 4-6 describe various ways in which the data can be extracted for transmission to the LCGS. For Options 1, 2, and 3, the scanner provides data directly to the LCGS data processor whereas in the case of Option 4, the fully formatted bit stream as output from the MOMS is routed to the LCGS data processor. Options 4 and 5 differ, since in the one case data reduction is achieved by discarding samples while in the other case the samples are averaged. Table 4-1 briefly describes the operation of each approach and includes a comparison of the hardware complexity for each.

Additional constraints are placed upon the data processor because of the desirability of including the thermal band data in all options as well as permitting the processor to operate at night when the MOMS is not powered.

4.3 SYSTEM PARAMETER TRADEOFFS

There are obviously several ways in which the data rates can be reduced to be compatible with the available transmission links. Various combinations of system parameters such as spatial resolution and percentage of both swath width and bands are tabulated in Tables 4-2 and 4-3 for transmission data rates of 4.4 and 18 Mbps, respectively. Figure 4-7 shows a functional block diagram of the recommended LCGS Data Processor.
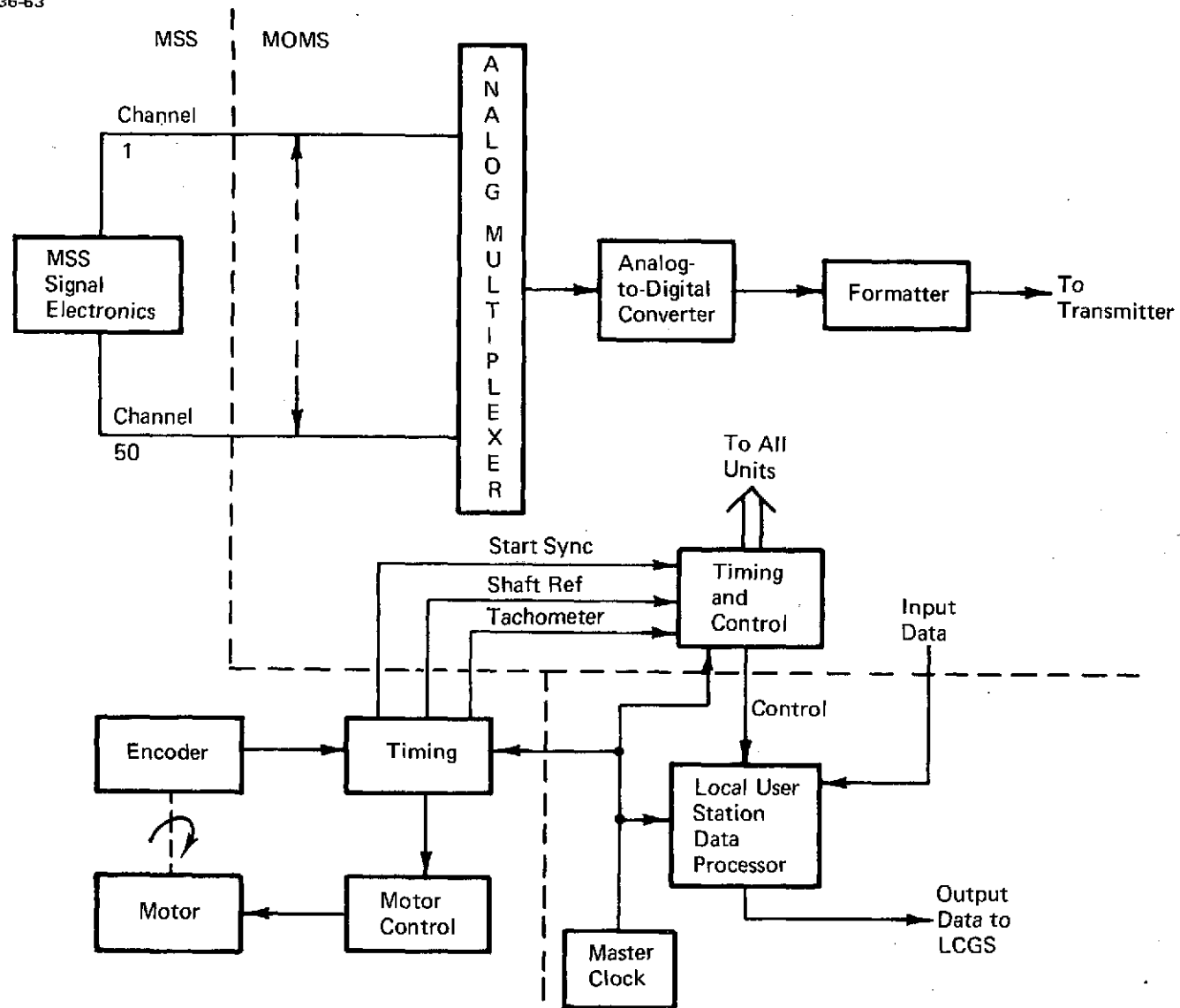
12136-63

Figure 4-2 Scanner/Spacecraft Data Handling Functional Block Diagram

12136-64
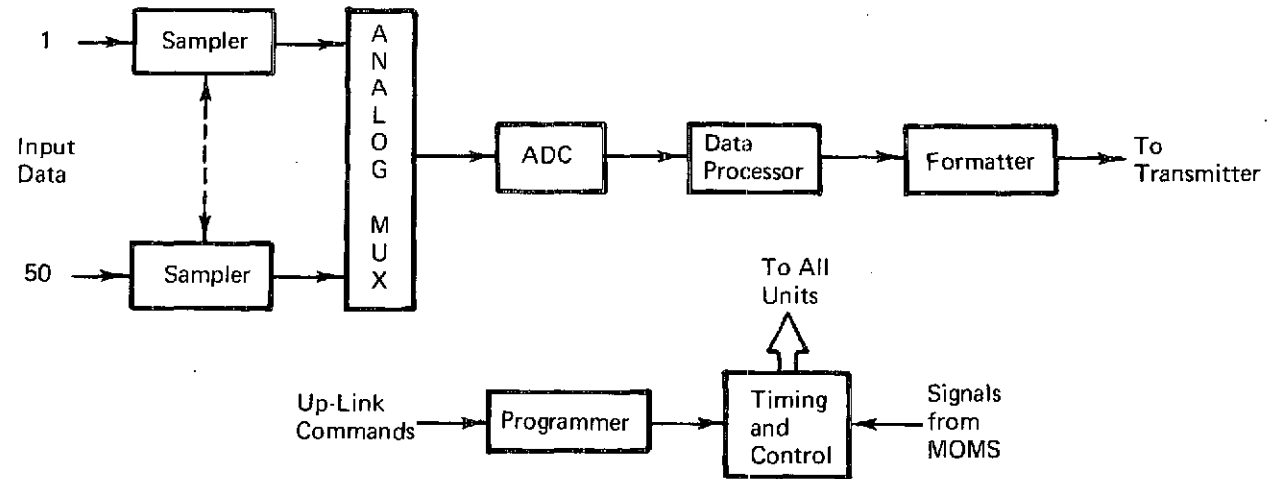
Figure 4-3 Option 1

12136-65
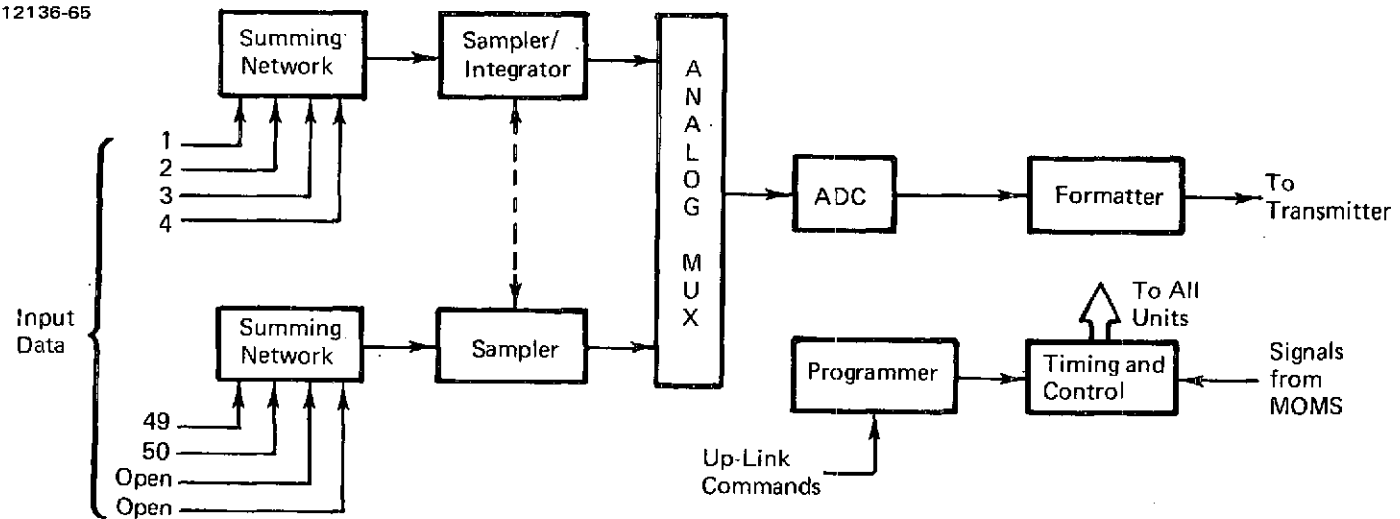
Figure 4-4 Option 2
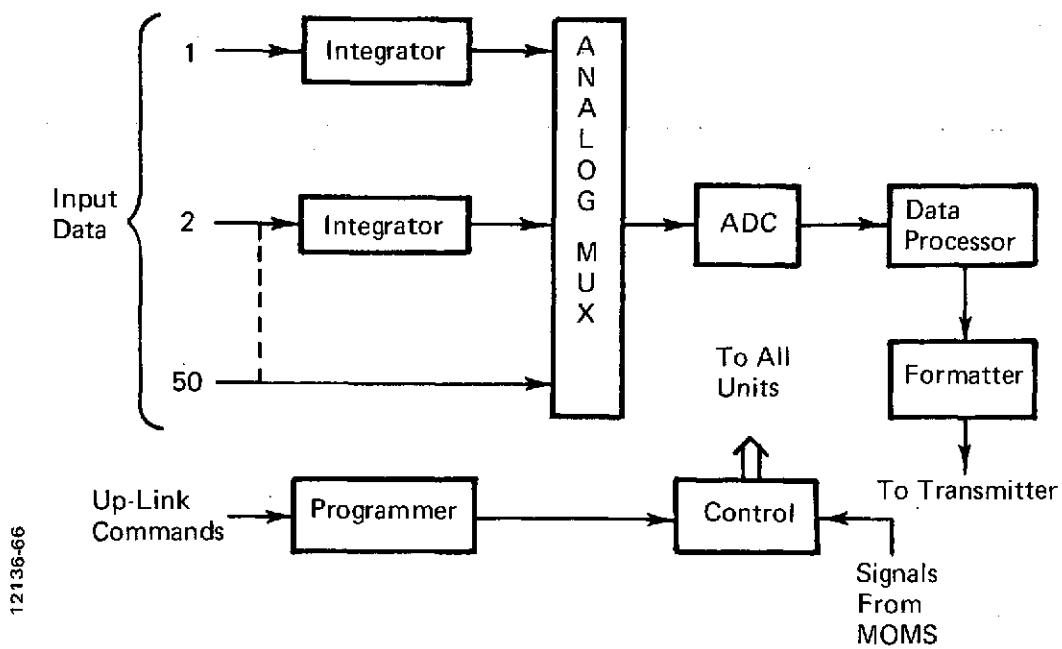
Figure 4-5 Option 3
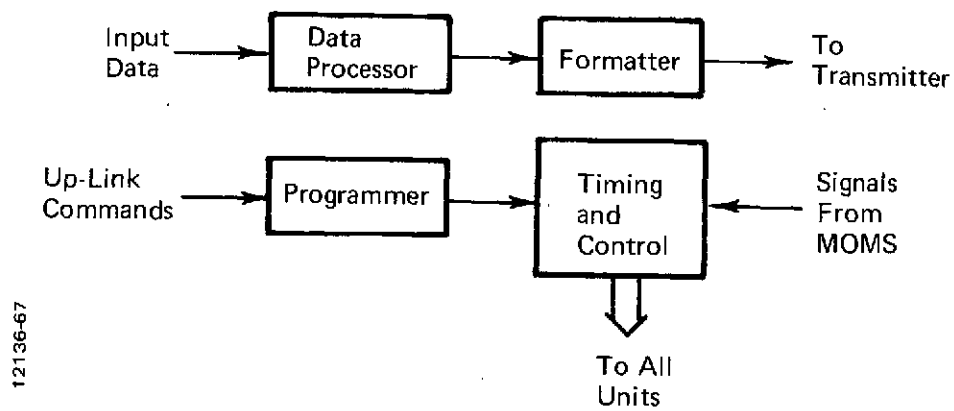
Figure 4-6 Option 4

Table 4-1

Hardware Complexity Comparison

Option	Technique	Data Reduction	Hardware		Comments
			Functions	Complexity	
1.	Separate samplers for each channel	Data reduced after being digitized with lower sampling rate	-Sampler (50 -Analog multiplexer -ADC -Data processor -Timing and control	-Above average -Extreme -Extreme -Above average -Extreme	. Very good imagery . Hardware approaches complexity of MOMS . Very costly and complex system
2.	Separate sampler which sums multiple channels	Data from four channels summed and sampled at less than normal rate	-Summing network (13) -Sampler (13) -Analog Multiplexer -ADC -Timing and control	-Above average -Above average -Above average -Above average -Above average	. Excellent imagery . Hardware complexity . less than for Option 1 . Simplified digital circuitry
3.	Sampler is common to that used for MOMS	Data sampled at normal rate within MOMS and successive samples integrated, four adjacent channels combined digitally	-Integrator (50) -Analog multiplexer -ADC -Data processor -Timing and control	-Extreme -Extreme -Extreme -Above average -Extreme	. Very good imagery . Hardware complexity approaches that of Option 1
4.	Digitized MOMS data are utilized	Digitized data sampled at normal rate are reduced slightly	-Data processor -Timing and control	-Extreme -Extreme	. Very good imagery . No analog hardware with requirement for very fast digital circuitry
5.	Digitized MOMS data are utilized	Digitized data sampled at normal rate are reduced by skipping cells and lines	-Data processor -Timing and control	-Simple -Extreme	. Poor imagery . Simplest hardware

Table 4-2

LCGS Onboard Processor Potential Configurations
for a 4.4-Mbps Data Link

No	Bands	Band Resolution	Spatial Resolution Lines	Spatial Resolution Samples	Data Rate (Mbps)	Possible Options	Swath Width	Buffer Size (Lines)	Comments
1	1	L	1	1	1.1	1 and 4	Full	-----	
2	1	H	1	1	17.5	1 and 4	<1/4	2	Delay data 1/4 line
3	2	1L & 1H	1	1	18.6	1 and 4	<1/4	2	Transmit low res. data direct, delay high res. data
4	2	1L & 1H	2	2	4.65	1,2,3,4	Full	1/8	Transmit high res. data & delay low res. data
5	2	2H	2	2	8.75	1,2,3,4	5/8	1	Transmit 1 band direct & delay 2nd band
6	2	2H	4	2	4.38	1,2,3,4	Full	-----	
7	1	H	1	1.6	1.1	1	>3/8	<2	Delay data 3/8 line
8	3	1L & 2H	1	1	36.1	1 and 4	<1/8	2	Delay both high res. bands
9	3	1L & 2H	2	2	9	1,2,3,4	1/2	1	Delay the low & one high res. band
10	3	1L & 2H	2	4	4.5	1,2,3,4	Full	1/4	Delay low res. band
10a	3	1L & 2H	4	2	4.5	1,2,3,4	Full	1/4	Delay low res. band
11	3	3H	2	4	6.57	1,2,3,4	5/8	5/8	Delay one band
12	3	3H	2	3	8.75	1,2,3,4	1/2	1 1/3	Delay 2 bands
13	4	1L & 3H	2	2	13.4	1,2,3,4	1/3	1 1/3	Delay 2 high res. & 1 low res.
14	4	1L & 3H	2	3	9	1,2,3,4	1/3	1 1/3	Delay 2 high res. & 1 low res.
15	4	1L & 3H	2	4	6.9	1,2,3,4	5/8	3/8	Delay 1 high & 1 low res. band
16	4	1L & 3H	4	2	6.9	1,2,3,4	5/8	3/8	Delay 1 high & 1 low res. band
17	4	4H	2	2	17.5	1,2,3,4	<1/4	1 1/2	Delay 3 high res. bands
18	4	4H	2	3	11.7	1,2,3,4	>1/4	2/3	Delay 3 high res. bands
19	4	4H	2	4	8.75	1,2,3,4	<1/2	1	Delay 2 bands
20	4	4H	4	4	4.38	1,2,3,4	Full	-----	Real time transmission
21	5	1L & 4H	2	3	12.2	1,2,3,4	3/8	1 1/2	Delay 3 high res. bands & low res. bands
22	5	1L & 4H	4	4	4.4	1,2,3,4	Full	1/32	Delay low res. band
23	5	5H	4	4	5.47	1,2,3,4	<Full	1/2	Delay one band
24	6	1L & 5H	2	3	14.7	1,2,3,4	>1/4	1 2/3	Delay 4 high res. & low res. bands
25	6	1L & 5H	2	4	11.0	1,2,3,4	1/2	1 1/2	Delay 3 high res. bands & low res. band
26	6	1L & 5H	4	2	11.0	1,2,3,4	1/2	1 1/2	Delay 3 high res. bands & low res. band
27	6	1L & 5H	4	4	5.5	1,2,3,4	9/10	1/2	Delay low res. & 1 high res. band
28	7	1L & 6H	2	4	13.3	1,2,3,4	1/3	1/2	Delay low res. & 4 high res. bands
29	7	1L & 6H	4	2	13.3	1,2,3,4	1/3	1/2	Delay low res. & 4 high res. bands
30	7	1L & 6H	4	4	6.6	1,2,3,4	2/3	2/3	Delay low res. & 2 high res. bands
31	7	1L & 6H	4	6	4.4	1,2,3,4	Full	1/48	Delay low res. band

Table 4-3

LCGS Onboard Processor Potential Configurations for an 18-Mbps Data Link

| No.	Bands	Band Resolution	Spatial Resolution		Data Rate (Mbps)	Possible Options	Swath Width	Buffer Size (Lines)	Comments
			Lines	Samples					
1	1	L	1	1	1.1	1 and 4	Full	-----	
2	1	H	1	1	17.5	1 and 4	Full	-----	
3	2	1L and 1H	1	1	18.6	1 and 4	Full	1/2	Delay low resolution band
4	2	1L and 1H	2	2	4.65	1,2,3,4	Full	-----	
5	2	2H	2	2	8.75	1,2,3,4	Full	-----	
6	2	2H	4	2	4.38	1,2,3,4	Full	-----	
7	1	H	1	1.6	1.1	1	Full	-----	
8	3	1L and 2H	1	1	36.1	1 and 4	1/2	8 1/2	Delay low resolution and one high resolution bands
9	3	1L and 2H	2	2	9	1,2,3,4	Full	-----	
10	3	1L and 2H	2	4	4.5	1,2,3,4	Full	-----	
10a	3	1L and 2H	4	2	4.5	1,2,3,4	Full	-----	
11	3	3H	2	4	6.57	1,2,3,4	Full	-----	
12	3	3H	2	3	8.75	1,2,3,4	Full	-----	
13	4	1L and 3H	2	2	13.4	1,2,3,4	Full	-----	
14	4	1L and 3H	2	3	9	1,2,3,4	Full	-----	
15	4	1L and 3H	2	4	6.9	1,2,3,4	Full	-----	
16	4	1L and 3H	4	2	6.9	1,2,3,4	Full	-----	
17	4	4H	2	2	17.5	1,2,3,4	Full	-----	
18	4	4H	2	3	11.7	1,2,3,4	Full	-----	
19	4	4H	2	4	8.75	1,2,3,4	Full	-----	
20	4	4H	4	4	4.38	1,2,3,4	Full	-----	
21	5	1L and 4H	2	3	12.2	1,2,3,4	Full	-----	
22	5	1L and 4H	4	4	4.4	1,2,3,4	Full	-----	
23	5	5H	4	4	5.47	1,2,3,4	Full	-----	
23a	6	1L and 5H	2	3	14.7	1,2,3,4	Full	-----	
24	6	1L and 5H	2	4	11.0	1,2,3,4	Full	-----	
25	6	1L and 5H	4	2	11.0	1,2,3,4	Full	-----	
26	6	1L and 5H	4	4	5.5	1,2,3,4	Full	-----	
27	7	1L and 6H	2	4	13.3	1,2,3,4	Full	-----	
28	7	1L and 6H	4	2	13.3	1,2,3,4	Full	-----	
29	7	1L and 6H	4	4	6.6	1,2,3,4	Full	-----	
30	7	1L and 6H	4	6	4.4	1,2,3,4	Full	-----	
31	3	3H	1	2	26.2	1,3,and 4	>2/3	5 1/3	Delay one band
32	3	3H	2	2	13.1	1,2,3,4	Full	-----	
33	4	1L and 3H	1	1	26.7	1 and 4	>2/3	5 1/2	Delay low resolution and one high resolution bands
34	4	1L and 3H	1	2	13.4	1, 3, and 4	Full	-----	
35	4	4H	1	2	35	1 and 4	5/8	10	Delay two bands
36	4	4H	2	2	17.5	1,2,3,4	Full	-----	
37	5	1L and 4H	1	2	35.5	1, 3, and 5	1/2	8	Delay low resolution and two bands
38	5	5H	1	2	42.5	1, 3, and 5	3/8	9	Delay three bands
39	6	1L and 5H	1	2	43	1, 3, and 5	3/8	9 3/4	Delay low resolution and one band
40	7	1L and 6H	2	2	26.3	1,2,3,4	2/3	2 2/3	Delay low resolution and two high resolution bands
41	7	1L and 6H	2	3	17.5	1,2,3,4	Full	-----	

12136-68
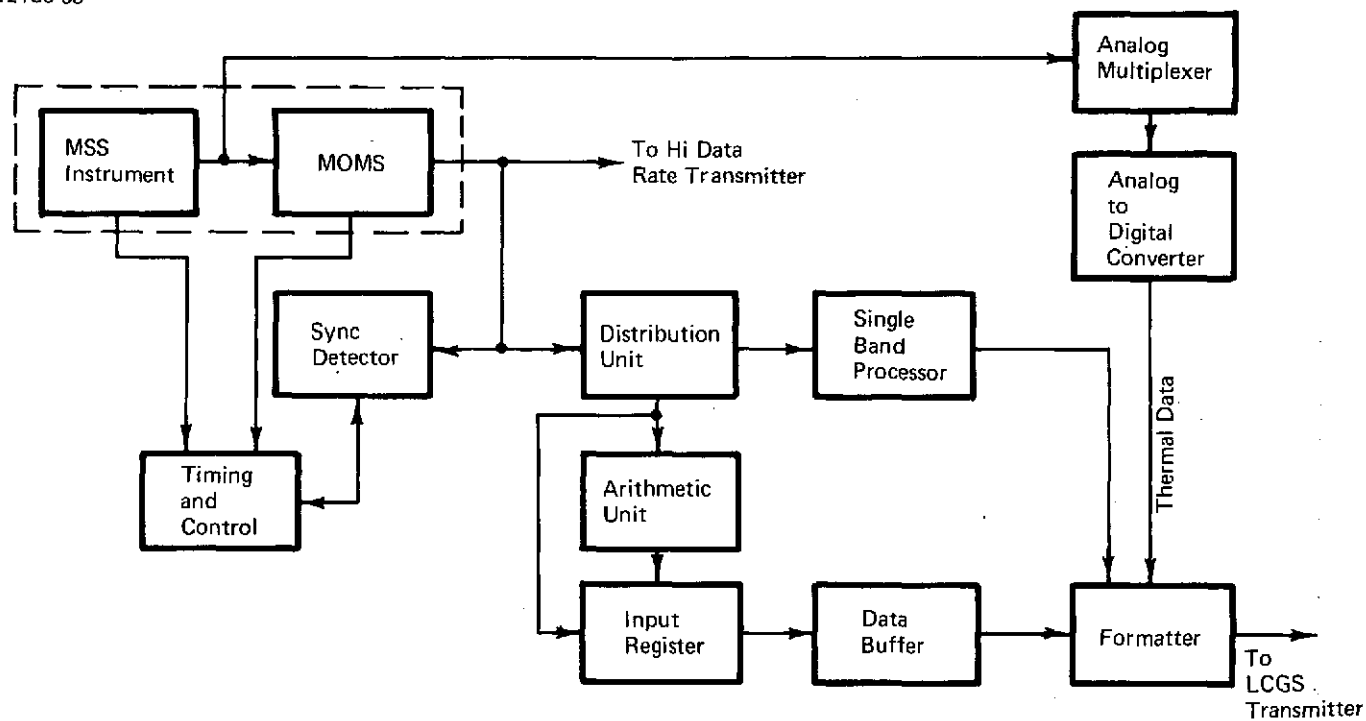
Figure 4-7   LCGS Data Processor Functional Block Diagram

4-11 (II)

The headings of each column in Tables 4-2 and 4-3 are described below:

No: Table entry number.

Bands: Number of bands from which data are collected.

Band Resolution: R for reflective band and T for thermal band.

Lines: Spatial resolution along spacecraft flight path, i.e., number of detectors whose outputs are combined.

Samples: Spatial resolutions along scan line in terms of the sample size used in MOMS, i.e., 1 sample corresponds to approximately 1.6 samples/cell.

Data Rate: This is the instantaneous data collection rate in megabits/ second.

Possible Options: This column references those hardware options as given in Figures 4-3 through 4-6 which could be utilized with minor modifications.

Swath Width: This is the fraction of the total swath from which data can be collected and subsequently transmitted.

Buffer Size: The buffer size required to permit the data to be trans- mitted at approximately the average rate rather than the instantaneous rates expressed in terms of lines of data. A line of data is equivalent to the amount of data obtained from a single detector at full resolution during a single scan (approximately 35 kilobits).

Many of these combinations are trivial, undesirable to a user, or difficult to implement. Because of the desirability of providing a reprogram- mable data processor, a grouping of three or four of these combinations can be easily selected to produce a system which can be implemented with ease.

An alternate method of presenting the same data is utilized for Figures 4-8 through 4-12. These figures are plots of average data rate (averaged over the swath width) as a function of quantity of bands for various spatial resolu- tions. In all cases, data from the thermal band are included.

After selection of a transmission link data rate, such as 4 Mbps, it is possible to obtain a plot (Figure 4-13) of the number of reflective bands versus percentage of swath width when full resolution data are collected by simply plotting the cross-over points from Figure 4-8. Corresponding curves are plotted on this figure for other values of spatial resolution. Similar data appear in Figures 4-14 through 4-16 for 8, 16, and 33 Mbps, respectively. These curves are useful in establishing upper limits for feasible combinations of spatial resolution, quantity of bands, and percentage of swath width for specific data rates. Corresponding plots can easily be generated for other data rates.
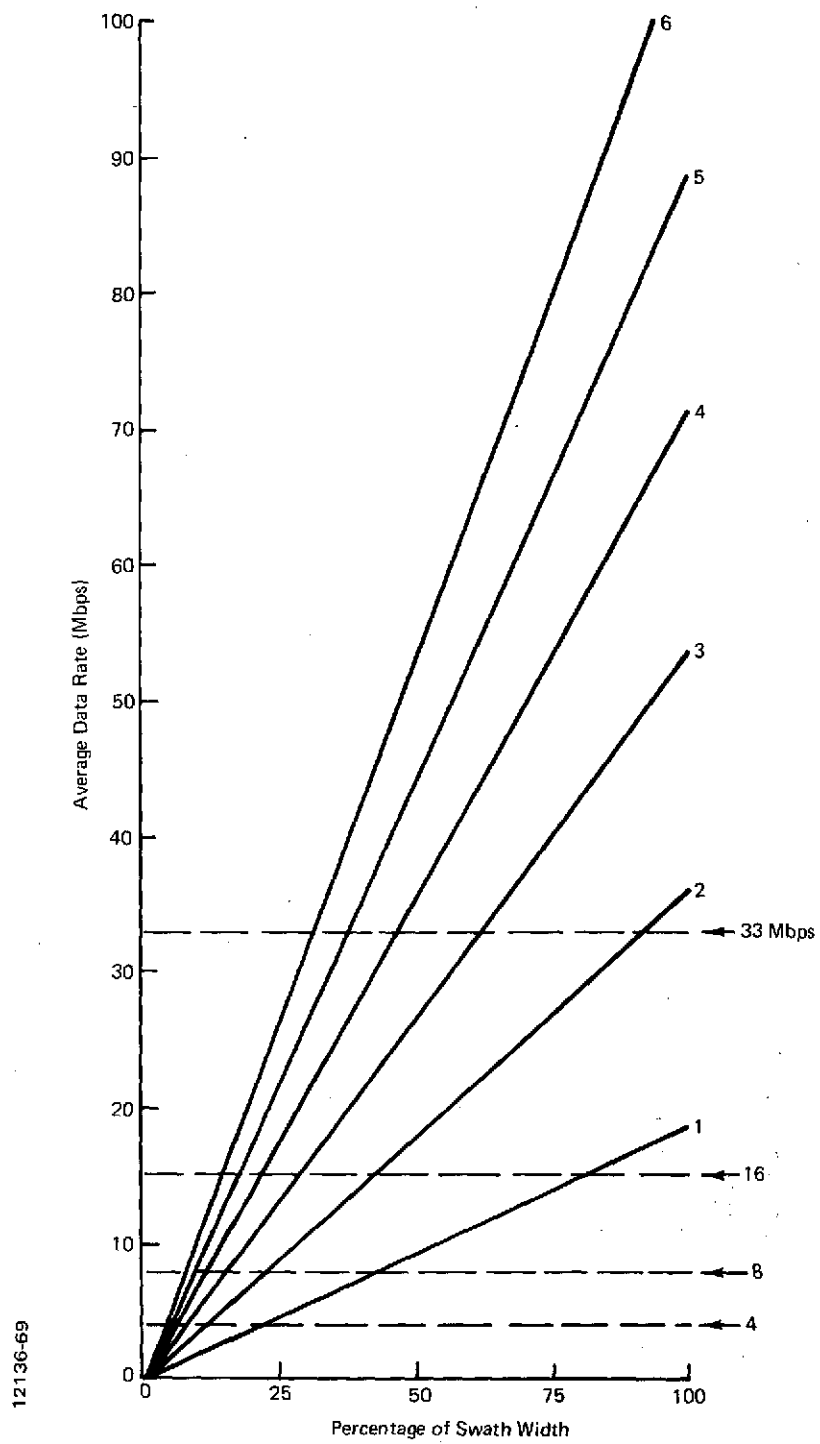
Figure 4-8 Average Data Rate Full Resolution

12136-69

4-13 (II)
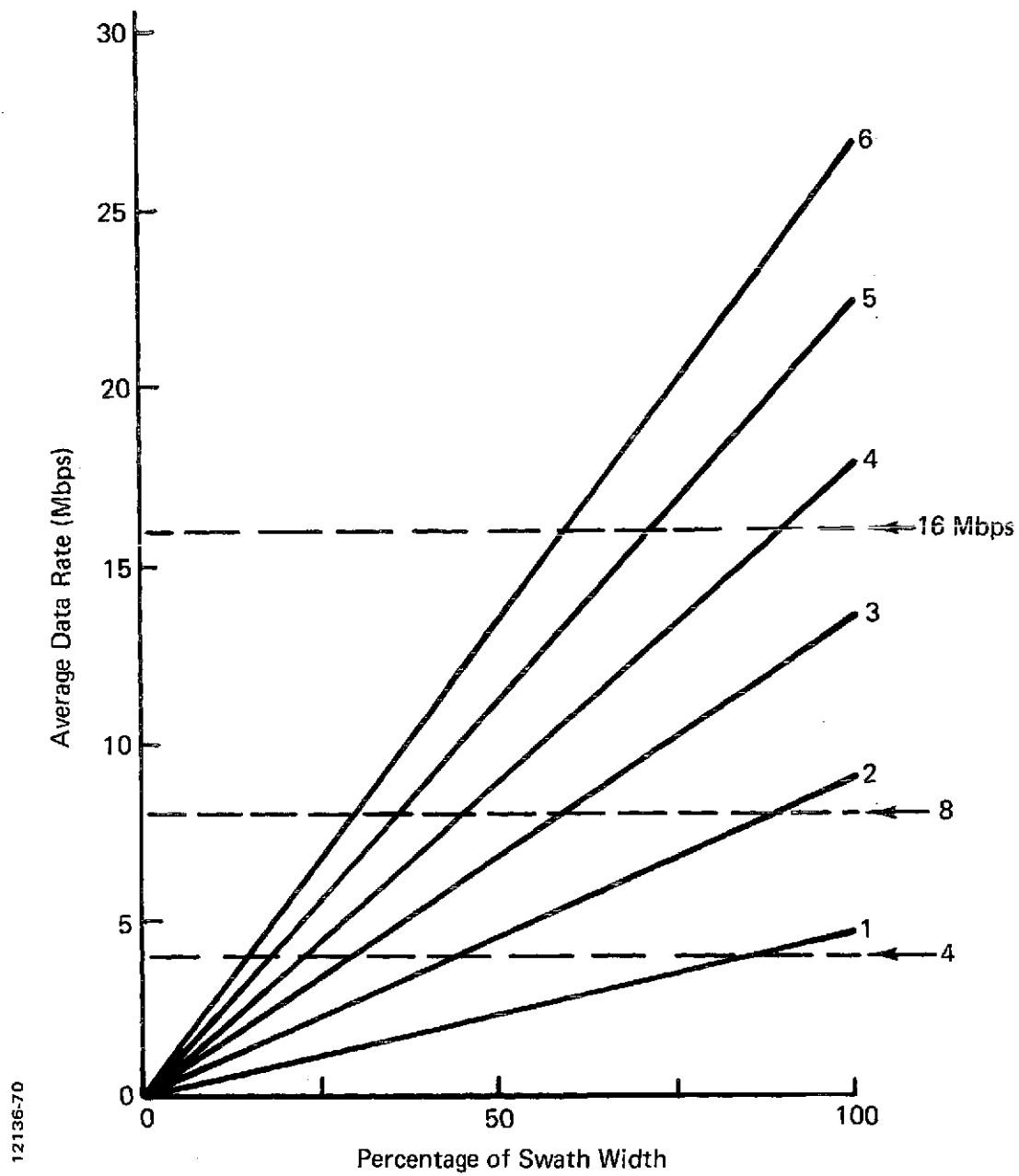
Figure 4-9 Average Data Rates - 2 Lines x 2 Samples

12136-70
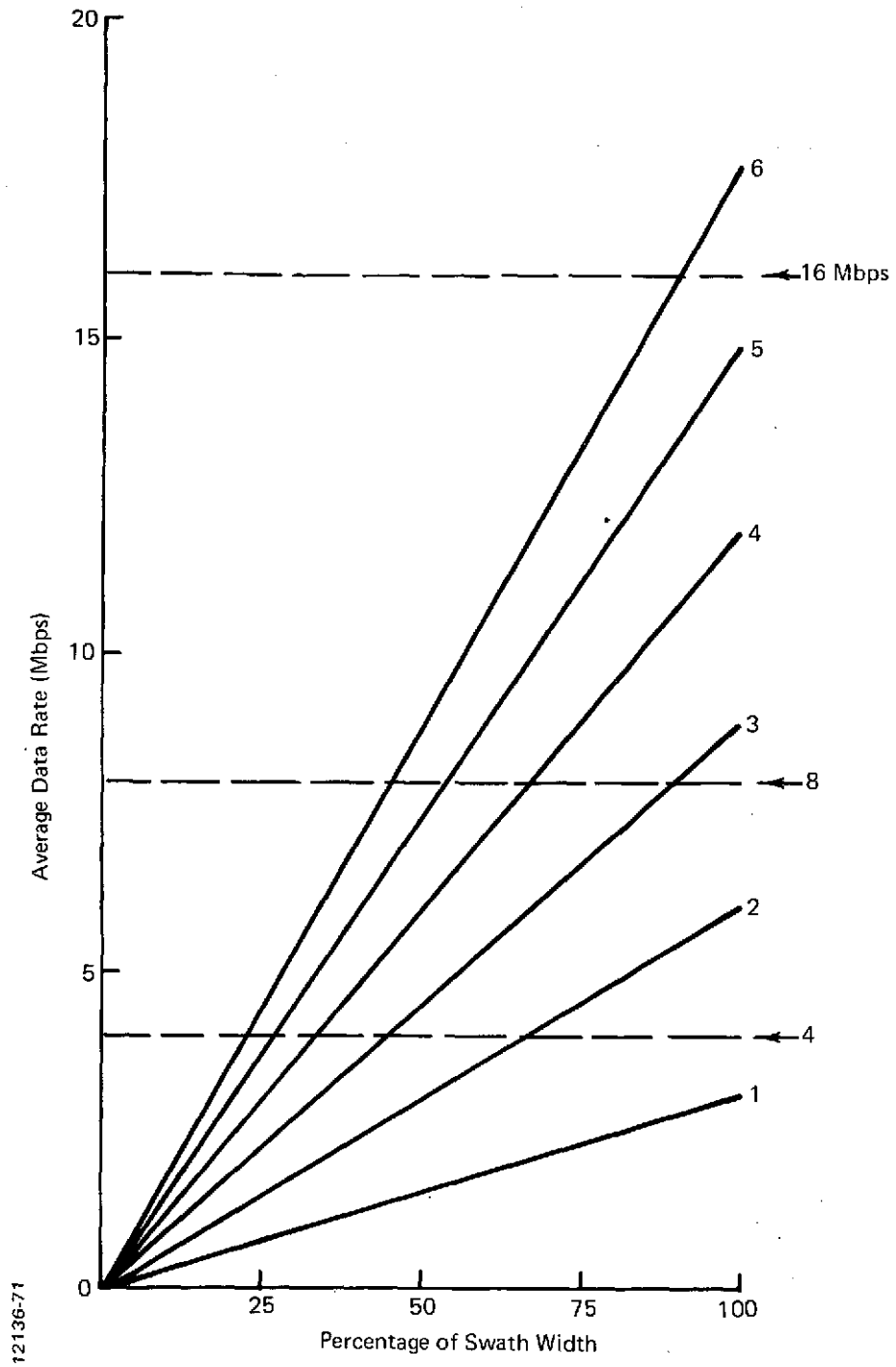
Figure 4-10 Average Data Rate - 2 Lines x 3 Samples
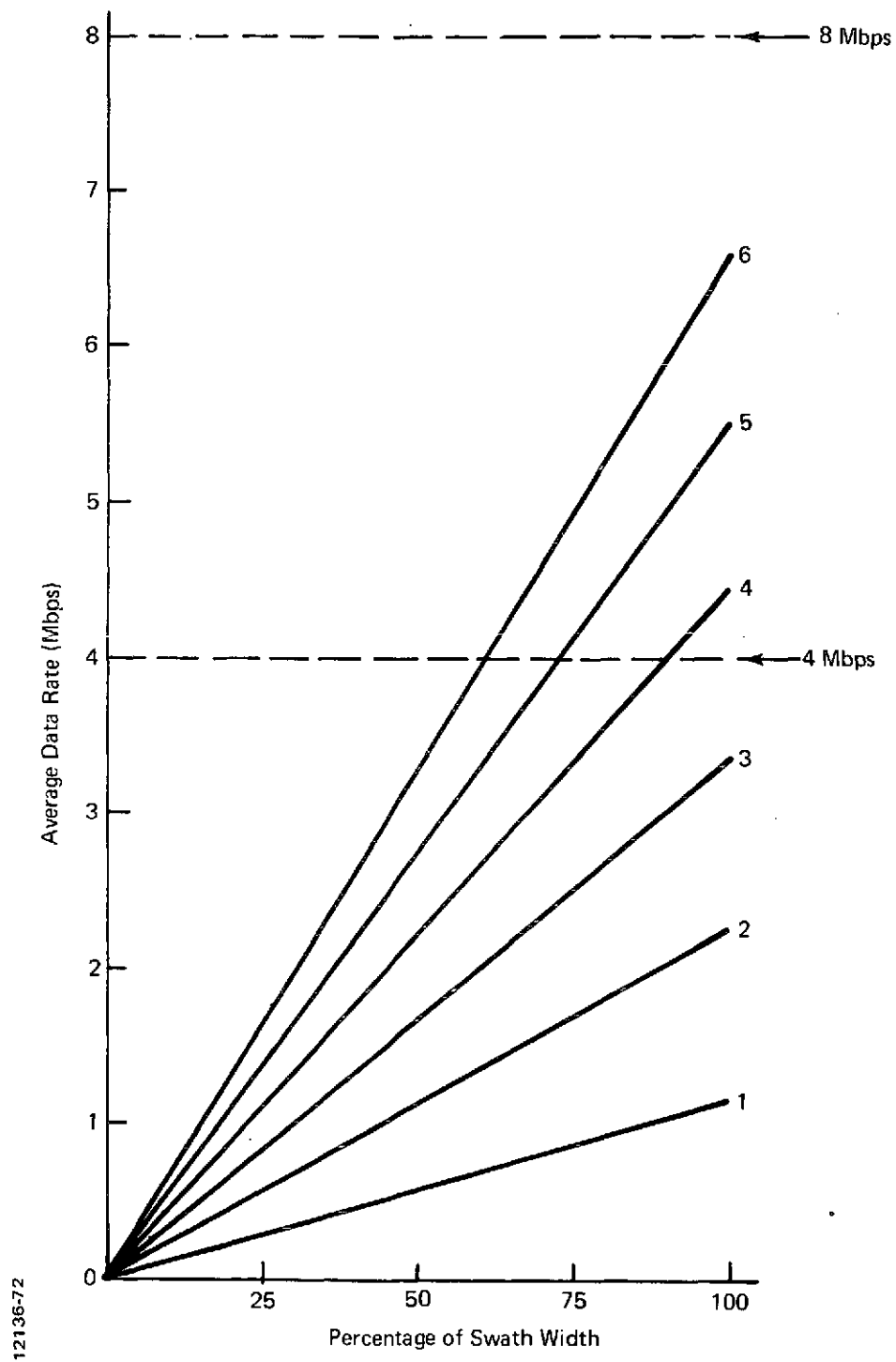
Figure 4-11 Average Data Rate - 4 Lines x 4 Samples

12136-72
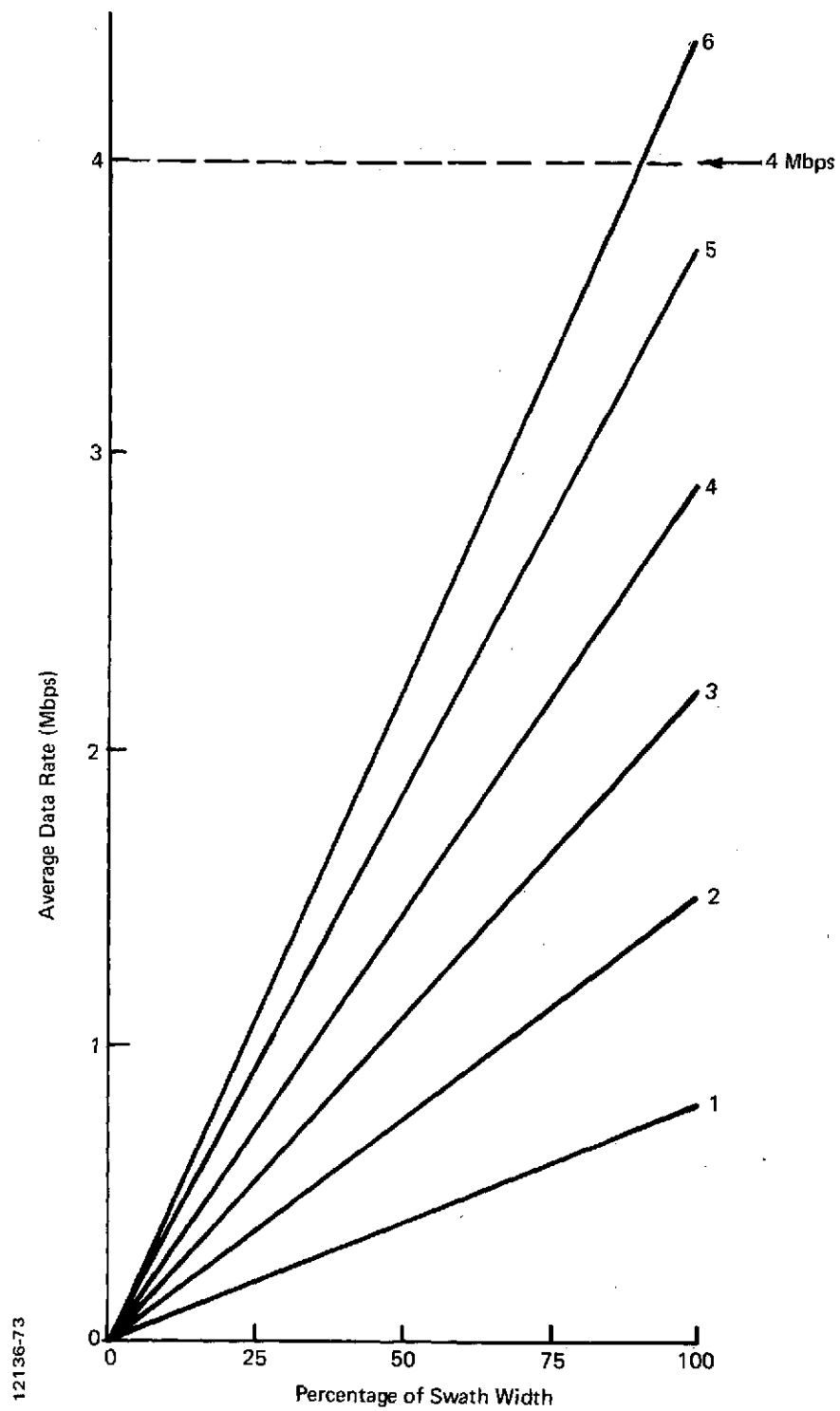
Figure 4-12 Average Data Rate - 4 Lines x 6 Samples
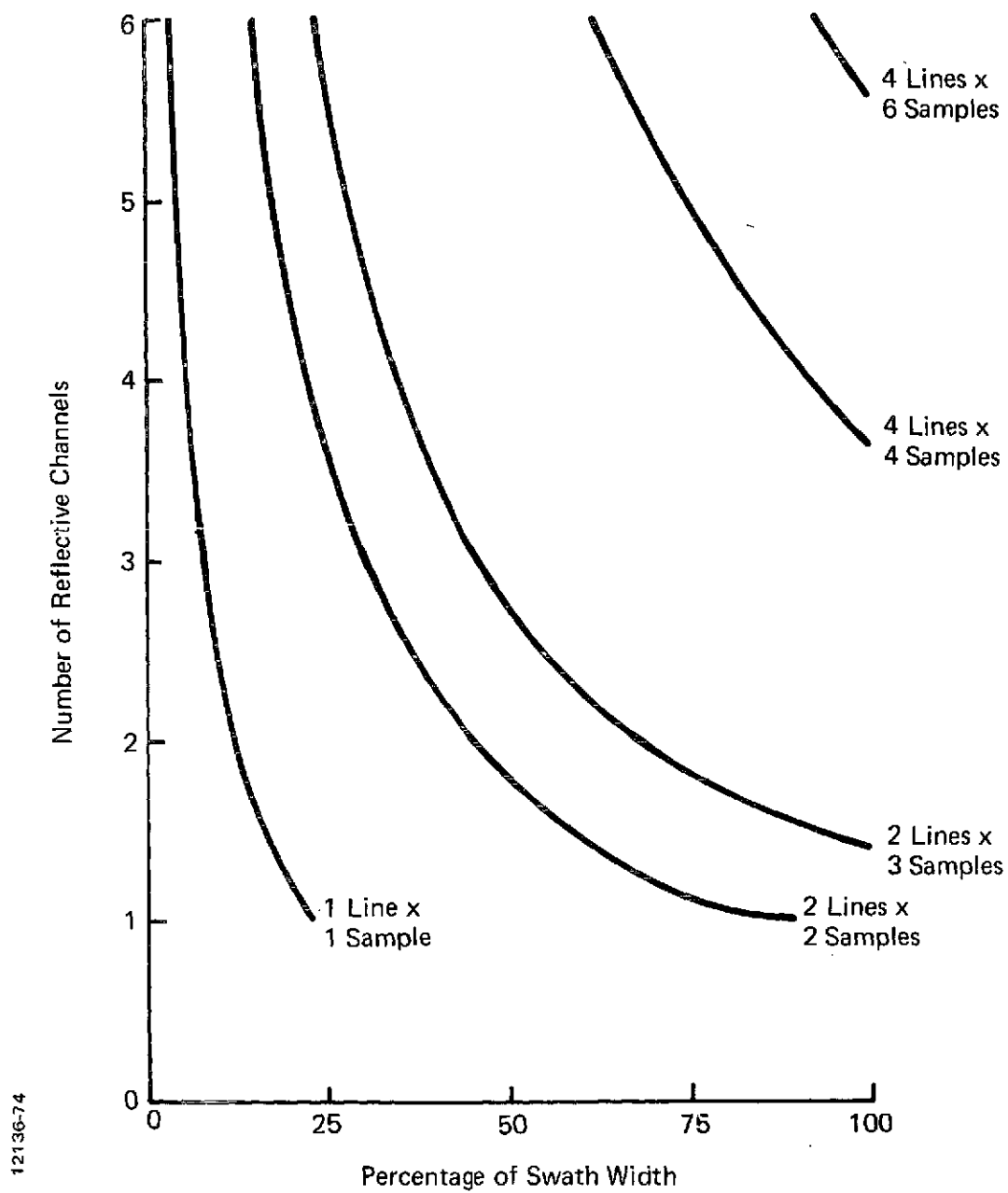
Figure 4-13 Data Processor Upper Limits for 4 Mbps
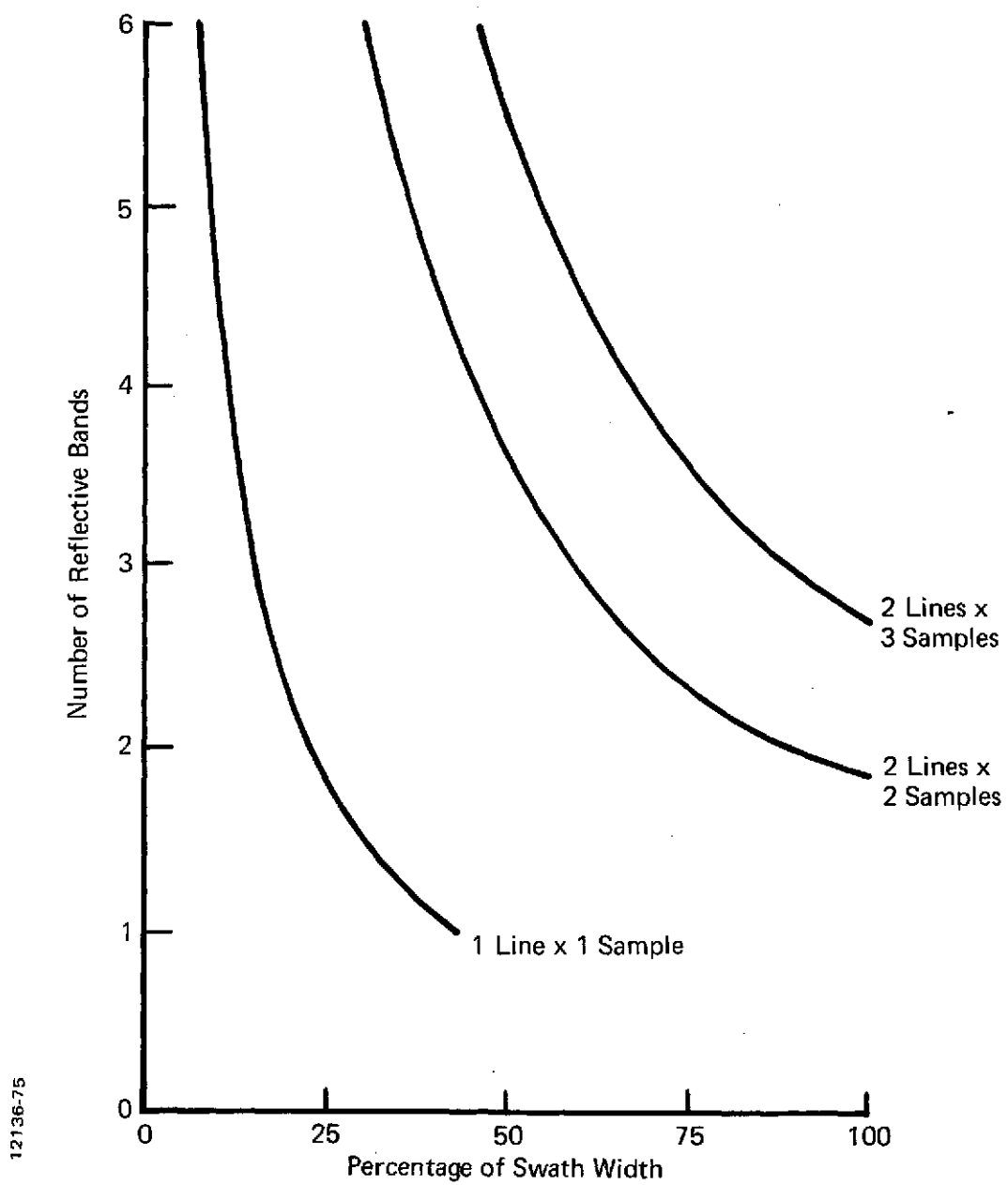
Figure 4-14 Data Processor Upper Limit for 8 Mbps
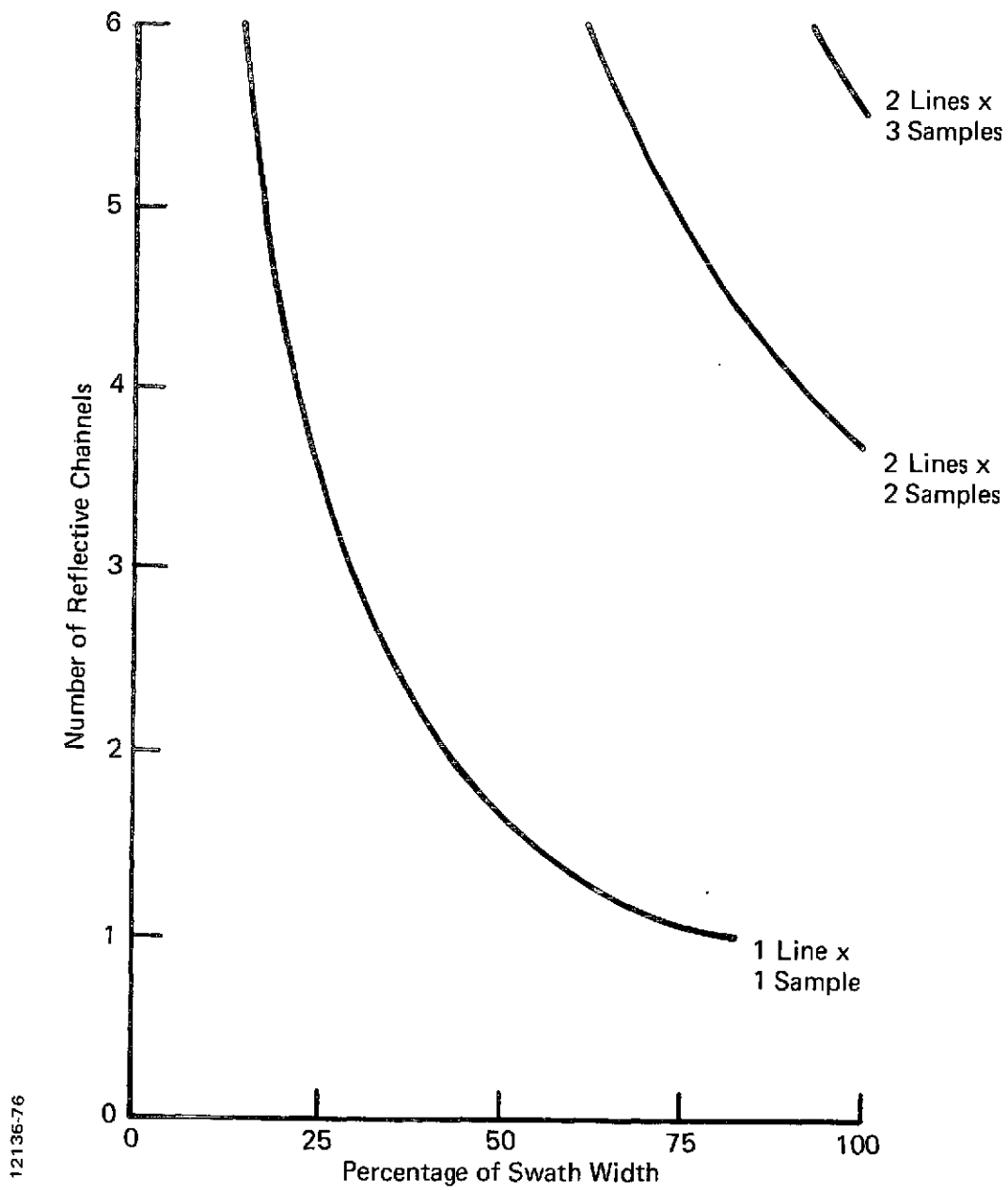
Figure 4-15 Data Processor Upper Limit for 16 Mbps
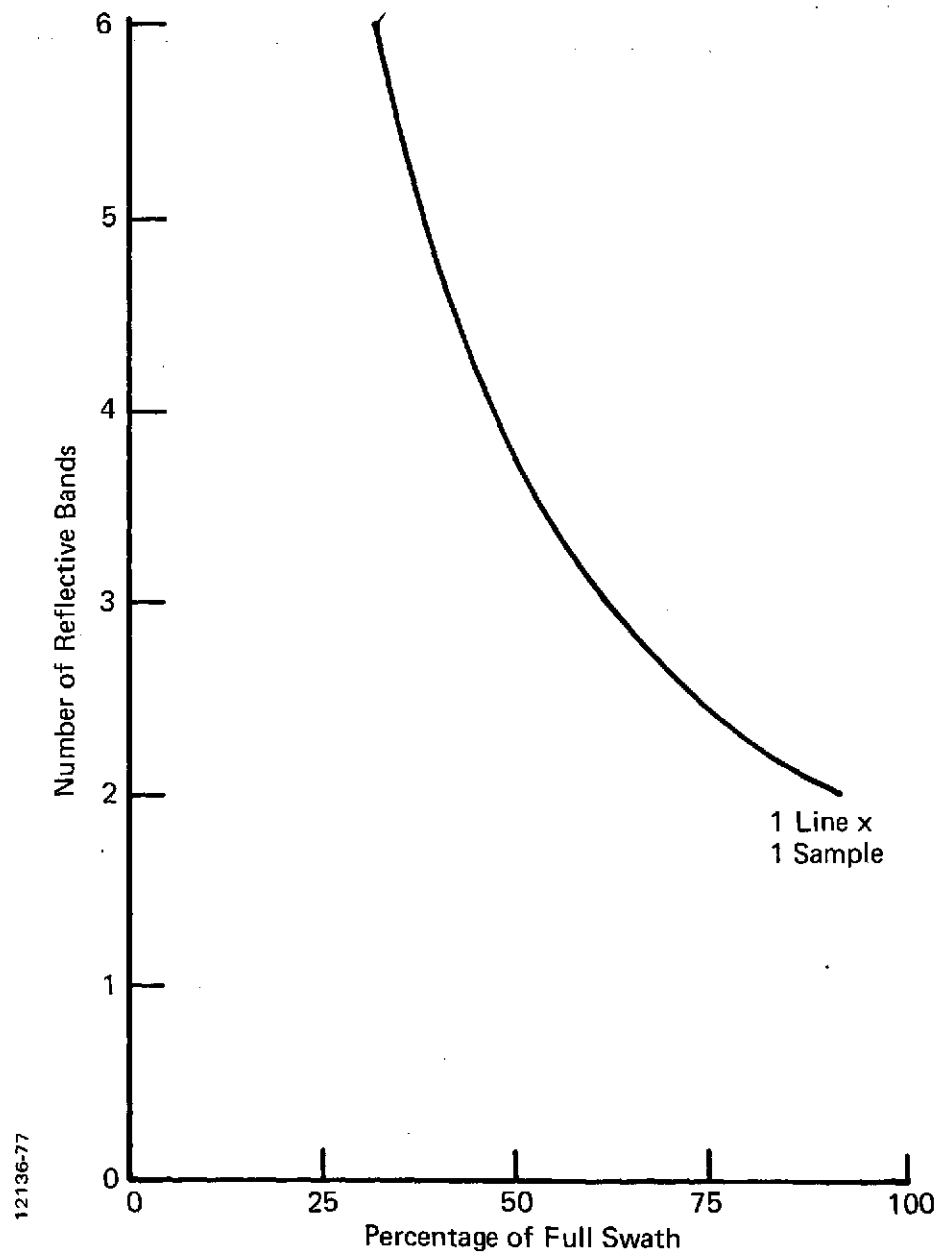
Figure 4-16 Data Processor Upper Limit for 33 Mbps

SECTION 5

GROUND DATA PROCESSING TRADEOFFS

Local user requirements for ground data processing differ markedly from the ground data processing required at the General Central Data Processing (GCDP) facility (such as the NDPF). While the central facility is concerned with the production of large quantities of data covering large geographic areas for many users, the LCGS needs to handle a small volume of data for a small set of users at any one time. Furthermore, the local user needs the ability to analyze the data and interact with the data and analysis through the LCGS. The LCGS therefore must perform different functions from the central facility at a considerably lower throughput rate. These functions are described in Section 5.1. Sections 5.2, 5.3, and 5.4 describe tradeoffs of three key system components (data recorders, film recorders, and data displays). Section 5.5 describes data processing system tradeoffs.

5.1   DATA PROCESSING FUNCTIONS

Local user processing of multispectral scanner (MSS) data in the LCGS encompasses the following functions:

- Data Recording and Playback.
- Data Demultiplexing.
- Interactive Display.
- Classification Processing.
- Geometric Correction.
- Radiometric Correction.
- Aperture Correction.
- Film Recording.

Each of these functions as related to the LCGS is described in the following paragraphs.

5.1.1   Data Recording and Playback

Fundamental to the concept of a low-cost local user system is the real-time recording of data for an area of user interest and data playback at a considerably reduced data rate to permit data processing in a simple low-cost data system. The data are retained in digital form through record and

playback to maintain data quality. The data are recorded in raw, unprocessed form to permit the user's repeated playback for interactive processing and display and film recording of individual spectral bands or processed combinations of spectral bands. Data recorders for implementing this function of the LCGS are described in Section 5.2.

5.1.2 Data Demultiplexing

In the processes of sampling the detectors in the multispectral scanner and formatting the sampled data for transmission over a single radio communication link, several multiplexing functions are performed in the spacecraft. These functions are highly dependent on geometric and spectral characteristics of the specific MSS design used. The normal design approach used is to multiplex the data in a manner leading to the simplest hardware design for the spacecraft electronics. On the ground, the LCGS must demultiplex the serial data stream, rearranging the data into a format convenient for data processing. Most of the spacecraft MSS designs under consideration scan more than one scan line at a time with a multidetector array. This places the data in a time sequence that is incompatible with generally available data output devices, which inherently are single-line-at-a-time devices. A major function of the LCGS is this demultiplexing function.

5.1.3 Interactive Display

The interactive display function of the LCGS permits the local user to perform operations of data screening and editing, training sample selection and extraction, and monitoring and evaluation of data processing results. Data screening consists of display of data to the user, thereby permitting him to evaluate data area coverage, cloud cover, and data quality in a relative sense. Data editing operations permit the user to designate areas of interest to limit the data quantity and processing to only that data of actual interest. Training sample selection and extraction operations permit the user to designate to the LCGS computer specific geographic areas in the displayed data for which the target class is known. The computer can then extract and store the multiband data for the specified area. This stored, extracted data of known classification represents a "training sample," that is, a spectral characteristic sample of a known target class to be used in later classification processing.

5.1.4 Classification Processing

Classification processing of multispectral image data separates image data elements into classes according to their spectral reflectance characteristics. For example, in an agricultural application the data scene can be

categorized into different crop types or classes. As developed and applied by Bendix, the processing algorithm operates on each image element with a linear transformation to enhance classification, determine the probability density for each data class, and perform a maximum likelihood decision to determine which data class assignment is most likely. The processing coefficients for the linear transformations are determined by the Bendix-developed "canonical" analysis of extracted training samples of known target classes. The processing coefficients produced from canonical analysis result in linear transformations, which reduce the data variance within a selected class to unity and make the background data variance very large, thereby permitting near-optimal separation of each data class from the background including all other classes.

5.1.5   Radiometric Correction

Ideally, each data sample point, or pixel, recorded by a passive line scan instrument would be a measure of the reflectance of the terrain at this point (in reflectance bands) or the radiance of the point (in thermal bands). Such ideal data would maximize the ability to categorize terrain pixels into classes corresponding to unique spectral reflectances as described in Section 5.1.3. It would also maximize the ability to temporally and spatially compare and correlate these classifications. Departures from this ideal are caused by sensor and environment-induced errors described in this section. Sensor responsivity errors can be corrected from data obtained during ground calibration or periodically from onboard calibration source data transmitted to the ground with the image data. These errors change slowly if at all and are readily corrected in ground data processing. Environment-induced errors result from the effects of, and variations in, atmospheric and sun irradiance characteristics. These errors can also be readily corrected in ground data processing, provided the necessary local environment data measurements are made at the time the MSS data are recorded. There are presently several ERTS experiments investigating techniques for collecting the necessary calibration data and for performing corrections for environment-induced errors.

5.1.6   Aperture Correction

Aperture correction consists of the compensation of total system effects that degrade spatial frequency response of the image data. These effects are functions of system elements including sensor optics, detector size, detector integration time, and video amplifier response. If the data are outputted on film, an additional element of aperture correction is required, that of compensating for the shape of the recording spot of the film recorder.

Once aperture correction is performed, the modulation transfer function (MTF) of the system should be near unity for all spatial frequencies present in the image. The degree to which unity MTF can be obtained is a function of the system MTF and signal and noise spectra. Aperture correction is implemented by "combing" the data with a function derived from the inverse MTF curve of the system and incorporating a noise compensation filter.

5.1.7 Geometric Correction

Geometric errors introduced into satellite-borne line scan sensor imagery arise from earth orbit geometric considerations, scanner geometry considerations, ephemeris and attitude perturbations, other scanner instrument design considerations, and scanner instrument electromechanical perturbations. The geometric errors, their magnitudes, and corrections are described in detail in Volume I of this study related to the General Central Data Processing Facility. Correction techniques described therein in Section 5 are applicable to the LCGS. In the LCGS, however, these corrections would be implemented in software for the data analysis system instead of special-purpose hardware. The rather substantial throughput penalty thus incurred is of no consequence for the LCGS.

5.1.8 Film Recording

In most applications the user of MSS data requires a hard copy image of data as an end product. This image may be of single spectral bands to be interpreted visually or computer-enhanced or classified combinations of bands as a direct "land use" image or map overlay. Film recorders for implementing this function of the LCGS are described in Section 5.4.

5.2 DATA RECORDERS

The data recorder in a local user ground data processing system is a key system element that stores the large quantity of data received from each overflight for repeated playback during processing and film recording and that acts as a rate buffer, permitting reduced data rate processing of data received at a very high rate. The combination requirement for large data capacity, high recording data rate, and low playback data rate results in the recorder being one of the most expensive single items in the data processor system. The recorder requirements in terms of total storage required, recording time as a function of selected data rates, and orbital distance covered are shown in Figure 5-1. Two basic types of tape recorders can meet the overall LCGS recorder requirements — instrumentation tape recorders and video tape recorders.
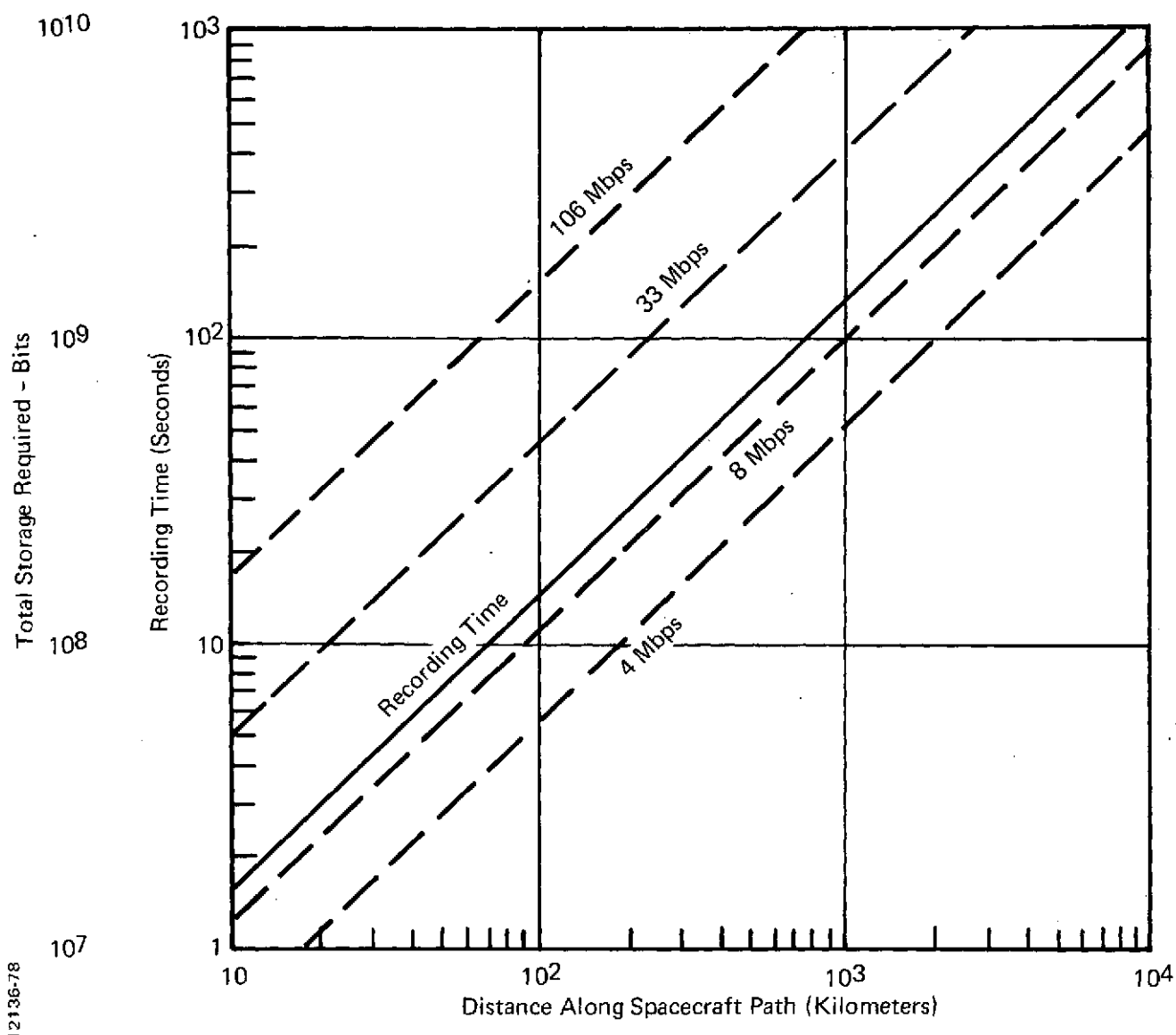
Figure 5-1 Recorder Storage Requirements

Available or projected instrumentation recorders either conform to the Inter-Range Instrumentation Group (IRIG) standards or are nonstandard. There are several manufacturers of IRIG standard machines, some of which are available with high-density digital tape (HDDT) recording electronics. Table 5-1 summarizes the general characteristics of this class of recorder.

Table 5-1

General Characteristics of IRIG Standard Tape
Recorders Applicable to LCGS Systems

Recorder Speeds: Multiple, 1 7/8 to 120 inches/second

No. of Tracks: 7, 14, 28

Bit Recording Density: Up to 20K bits per inch per track

Data Rates: Up to 2.4 Megabits/second/track

At present the IRIG standard recorders are expensive in terms of overall LCGS cost, ranging upward from about \$15,000 for a seven-track, two-speed unit capable of about 1.0 to 1.5 x 10^6 bits per second (bps) per track. The HDDT record and playback electronics required to multiplex tracks and encode each track for recording and, on playback, to bit, word, and frame synchronize, deskew, and interface to the LCGS computer can easily double the cost of the recorder subsystem. Subsystems of this type are state-of-the-art and are presently in use in many systems.

Non-IRIG standard instrumentation recorders recently became available. They are lower in cost and, because of higher bandwidth capability per track, require less costly interface electronics. One such unit, projected to cost about \$8,500 in small quantities, can record over 5 Mbps per track on up to eight tracks. In a typical LCGS application, this recorder would require only two channels of interface electronics. At the 5 Mb per channel rate this recorder can run for 30 sec, which is adequate for most LCGS configurations. For LCGS configurations requiring longer record time, the IRIG standard machines would be required.

Video tape recorders were also considered for LCGS applications. A rotating-head video tape recorder designed to record wideband television signals can be configured to record digital data. Presently, one unit is available capable of recording at a data rate of about 8 Mbps at a cost of about \$50,000. A smaller, cheaper unit is projected for the EOS time frame. This unit has

the disadvantage, however, that it must record and play back at the same speed and data rate. The playback and data input to the computer are rather awkward, since the unit must be operated in a start-stop mode for which it really is not designed. In this mode, one record of data would be brought into the computer and the tape unit stopped. While the computer processes the data, the tape drive would search for the next record. Because the machines are not basically designed for start-stop operation, data inputted in this way would be extremely slow. Very cheap rotary-head video tape recorders are available which could be modified to handle digital data. Video cassette recorders with a 4-MHz bandwidth are presently available for approximately $1,500. It is recommended that modification of these units for digital data and multispeed operation be investigated for LCGS applications.

5.3   FILM RECORDERS

In most applications of the LCGS, the final output product or result will be a film record of the processed data. This film record can present data to the user in various ways with film density and/or color representing the data as summarized in Table 5-2. The Electron Beam and Precision Color Laser Recorders are capable of producing film records at full EOS resolution and throughput. They are shown only to bound the film recording capability and are not considered as candidates for the LCGS because of their high cost.

All of the film recorders listed in Table 5-3 are applicable to the LCGS if EOS produces linear scan data. If the EOS MSS produces conical scan data, then only the Precision CRT/Camera recorder is applicable. The slaved CRT Display/Camera recorder may be applicable if a suitable curved line CRT display is developed; however, the resolution is very poor. The cost of the Precision CRT/Camera recorder depends on the characteristics of the precision CRT unit, ranging from $30,000 (ROM) for 1,000 TV lines/ frame to $80,000 (ROM) for 4,000 TV lines/frame.

Figure 5-2 shows the relationship between the number of resolution elements per scan line and the percentage swath width over which data are collected for full-resolution MSS data and reduced resolution achieved by combining resolution elements in the spacecraft. These curves are overlaid with the resolution capability of the film recorders described in Table 5-3. This figure therefore is a film recorder tradeoff curve, which is used in Section 7 in LCGS synthesis.
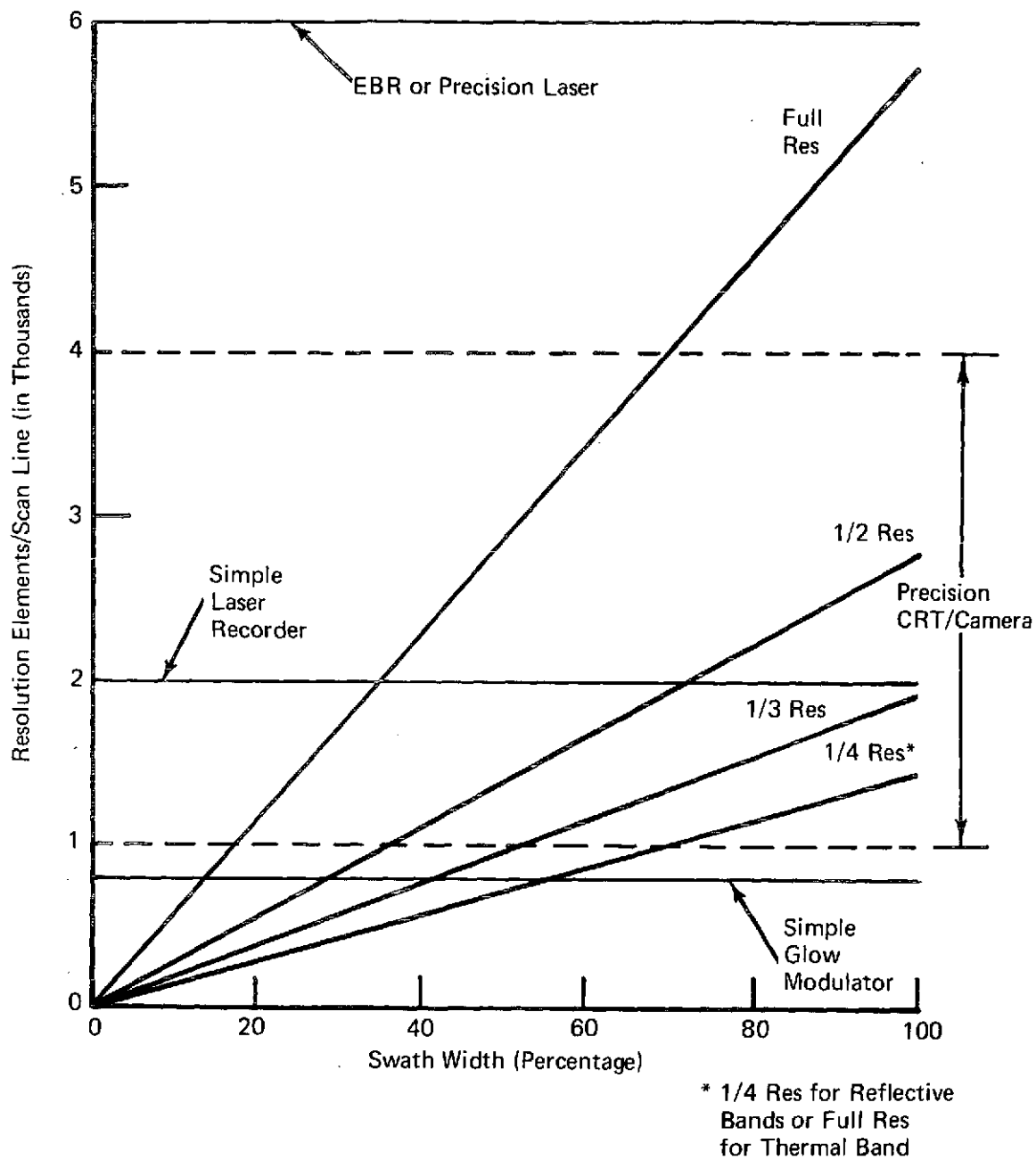
Figure 5-2 Film Recorder Tradeoff Curves

12136-79

Table 5-2

Film Recorder Data Representations

Black and White	1.	Single-band representation - Film density is a function of terrain reflectance or radiance.
	2.	Classified multiband representation - Gray levels represent different target classes.
Color	1.	Single-band representation - Color represents terrain reflectance or radiance.
	2.	Unclassified three-band representation - Three-band reflectance or radiance is recorded as varying intensity of red, green, and blue.
	3.	Classified multiband representation - Colors represent different target classes.

5.4 DATA DISPLAY

One of the prime attributes of the LCGS is interactive processing whereby the investigators or users can observe, modify, and evaluate the data processing operation and results. A near real-time data display is inherent in such operations. Table 5-4 summarizes the characteristics of candidate display units, and Figure 5-3 shows data resolution tradeoffs for these units.

Data display units as components of interactive earth resources data processing systems are composed of: (1) a flicker-free, refreshed, raster-scanned CRT display, (2) a refresh memory capable of storing at least one computer screen or frame of data, accepting the data at a low input rate, and outputting repeatedly at the video rate required for flicker-free display on the CRT, (3) a computer interface to permit data input and display from the computer, and (4) a cursor system to permit operator-interactive designation

5-9 (II)

Table 5-3

Film Recorder Candidates

Film Recorder Type	Resolution	Film Size	Color/ Black and White	Geometric Corrections Capability	Throughput or Frame Time	Format	ROM Cost $
1. Slaved CRT Display/ Camera	Same as Display Resolution (Less Than 500 TV Lines)	70 mm	Either	Same as Display	Time Required to Load Display Refresh Memory	Framing	15K
2. Simple Glow Modulator	800 TV Lines	70 mm	B & W	None	1 to 10 Scan Lines/ Sec	Continuous Motion	25K
3. Drum Scan	3,000 to 6,000 TV Lines	20.3 x 25.4 cm	B & W / Color Planned	None	10 Scan Lines/ Sec	Framing	29-33K / 45K
4. Precision CRT/ Camera	1,000 to 4,000 TV Lines	70 mm	B & W	Yes	25 Sec/ Frame	Framing	30-80K
5. Precision CRT/ Camera	4,000 TV Lines	4 x 5 in.	Color	None	1,260 Sec/ Frame	Framing	40K
6. Simple Laser	2,000 TV Lines	70 mm	Either	None	1 to 10 Scan Lines/ Sec	Continuous Motion	40-60K
7. Electron Beam	Up to 6,000 TV Lines	70 mm	B & W	Yes	25 Sec/ Frame	Framing or Continuous Motion	>300K
8. Precision Color Laser	Up to 6,000 TV Lines	70 mm to 9 1/2 in.	Color	None	25 Sec/ Frame	Continuous Motion	>300K

Table 5-4

Candidate Display Characteristics

Display Type	Color/ B & W	Resolution TV Lines	Display Mode	Cost[a] K$ (ROM)	Remarks
Scan Converter Tube/CRT	B & W	Up to 1,024	Framing	10	
Analog Disc/CRT	Either	Up to 525	Framing	20	Moving window mode and reduced cost possible with development.
Digital Disc/CRT	Either	Up to 525	Moving window and/ or framing	30 to 60 (262 to 525)	
Solid-State Memory/CRT	Either	Up to 525	Moving window and/ or framing	15 to 60 (262 to 525)	Solid-state memory will probably reduce in cost.

[a] Cost based on 6 bits per picture element.
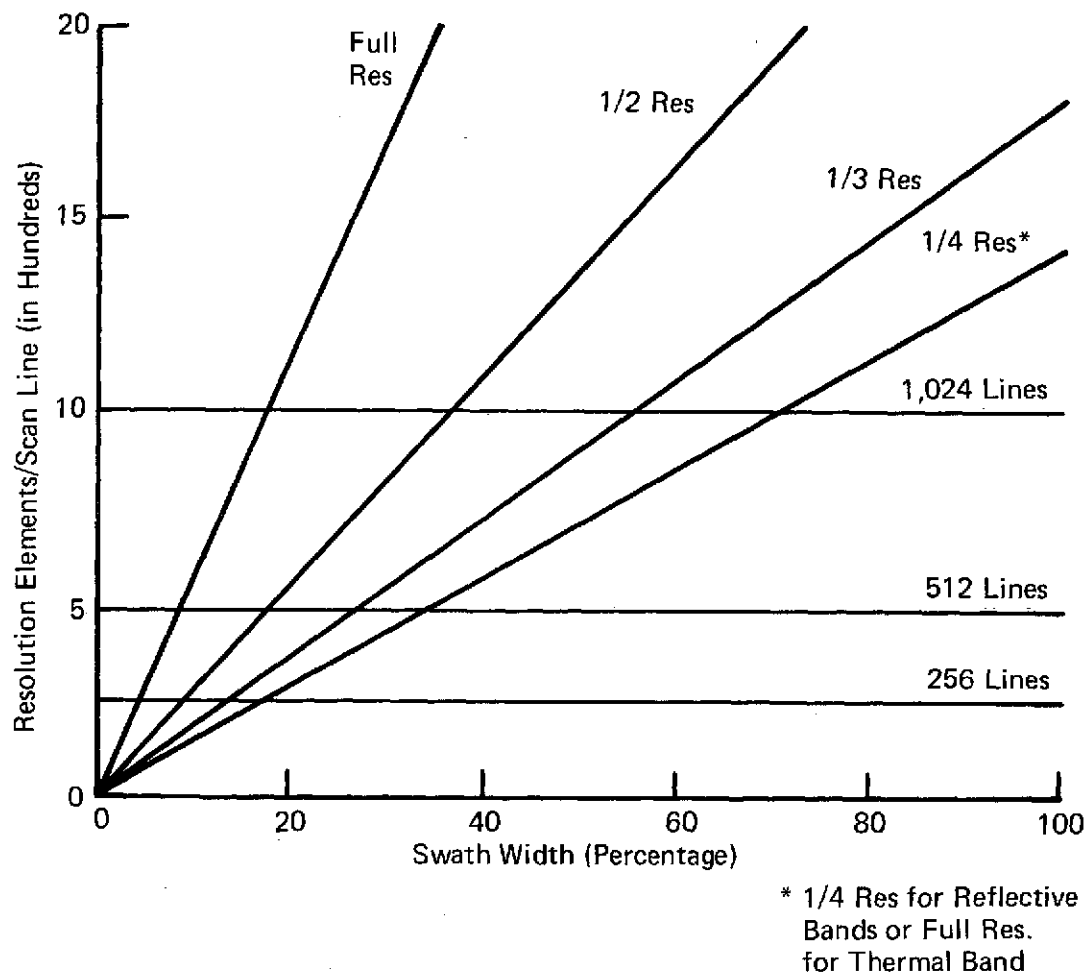
Figure 5-3 CRT Display Tradeoff Curves

to the computer of selected data displayed on the CRT screen. CRT display capabilities are largely limited by two factors — CRT resolution and size of the refresh memory. Color CRT displays commonly use standard 525-line color studio monitors, although 625-line European standard monitors could be used. Color monitors are limited mainly to these maximum resolutions by the color phosphor dot matrix or line pattern in the screen. Higher resolution color displays have been made by optically superimposing three primary color CRTs, but these are expensive and require critical alignment to achieve only moderate success. All presently available CRT monitors are of the linear raster scan type and are thereby only capable of adequate display of linear scanner data. Display of conical scan data requires either development of a variable scan format CRT monitor or linearization of conical scan data before display. Either of these alternatives is likely to be too expensive for the LCGS.

In a linear scan display system, the primary element of cost is the refresh memory. The principal components used as refresh memories are scan-converter tube, analog magnetic disc, digital magnetic disc, magnetic core, and solid-state memory.

An ideal display for interactive processing would be one which could display a large scene, perhaps 185 km by 185 km, in color, with the capability to "zoom" in on selected targets so that each resolution element displayed is recognizable. Such a display would permit location of training sites in the "big picture" and enlargement of these sites so that the training sample selection could be accomplished in a way which ensures that only training site data are sampled. A color display with these characteristics would be prohibitively expensive for an LCGS. Bendix's experience in display and processing of ERTS data has shown that there is an equally satisfactory way of operating with a cheaper low-resolution color display. With only the low-resolution display available, a map of the area to be covered is used to provide the "big picture" location of the training sites and ground control points (GCPs) and the display is used to locate precisely these sites and data. Suitable maps at a scale of 1:250,000 are available for the entire United States at a cost of about $500.00 per set. For areas where maps may not be available, it would probably be useful to augment the basic LCGS with a higher resolution black and white CRT display to permit the "big picture" location of training sites. As shown in Figure 5-3, a 1,024-line CRT could display 70% of the swath width at 1/4 full resolution. Such a black and white display could be added to the LCGS for about $10,000 (ROM).

5.5 DATA PROCESSING SYSTEMS

In data processing, the LCGS sacrifices data throughput and some functional capability relative to the capabilities of the GCDP facility in order to reduce the LCGS cost. Where the GCDP must process each full frame of data in about 30 seconds, 30 minutes or more per frame is satisfactory for the LCGS. In addition, normal processing functions will be considered to be data demultiplexing, radiometric correction, classification processing, and gross geometric correction. Aperture correction is considered to be a special processing function performed on a small percentage of the data. As a result of these tradeoffs, the LCGS data processor is a general-purpose minicomputer rather than the special-processor hardware used in the GCDP. The minicomputer system to accomplish this processing is described in Section 7.

SECTION 6

BASELINE SYSTEMS

From the results of the tradeoff studies described in Sections 3, 4, and 5, it is possible to define a number of baseline or candidate concept systems that meet varying levels of local user requirements. These baseline systems are described in this section. One specific baseline, a Low Cost Ground Station (LCGS), is further defined in Section 7.

6.1 BASELINE COMMUNICATIONS SYSTEMS

Preceding tradeoff studies have shown that the ground communications subsystem and the data recorder are pacing elements in terms of data capability and cost. Table 6-1 defines 10 candidate concept local user systems configured about various spacecraft and ground system antennas and ground system data recorders. The spacecraft antennas considered are a simple fixed antenna with a coverage radius on the ground of 115 km and a programmed-steered antenna with 30-dB gain. Ground antennas that were considered range from fixed hand-pointable units, to manually tracked units, to autotracked units. Data recorders considered were a small two-track high density digital tape (HDDT) capable of recording 8.0 Mbps, a 14-track IRIG standard HDDT capable of recording 33 Mbps, and an undefined unit capable of recording the full MSS data rate of 106 Mbps.

Representative data sample modes for each data rate are also listed in Table 6-1. The data sample modes selected and tabulated represent, for each of the reduced data transmission rates, useful combinations of spectral bands, resolution, and swath width. Other combinations as described in Section 4 could be selected; however, they must be selected so as to not produce data rates exceeding the transmission or recording capability. In Table 6-1 the nomenclature in the "Resolution" column is that 2 x 3 resolution means that each pixel transmitted is a synthesized resolution element made by averaging adjacent full-resolution pixels in the spacecraft, three elements along two adjacent scan lines. Each 2 x 3 pixel is composed of the average of six full-resolution pixels. Similarly, 4 x 4 resolution means that each 4 x 4 pixel is composed of the average of 16 full-resolution pixels, four along each of four adjacent scan lines. The communication coverage and data acquisition capability for each candidate system are illustrated in Figures 6-1 through 6-12.

Table 6-1

Communication Characteristics for Candidate Systems

Candidate Concept	Spacecraft Antenna	Ground Antenna	Communication Coverage Figure No.	Data Rate (Mbps)	Recorder Type	Representative Sample Modes			Figure No.
						Bands	Resolution (See Text)	Swath Width	
1	Fixed, 115-km Radius Coverage	Fixed-Pointable 4.5° Beam	6-1	8.0	Small HDDT	IR&T All T only All	Full 2 x 3 Full 4 x 4	40% 40% 100% 100%	6-2
2	Fixed 115-km Radius Coverage	Manually Tracked 4.5° Beam	6-3	8.0	Small HDDT	Same as Above	Same as Above	Same as Above	6-4
3	Fixed 115-km Radius Coverage	Autotracked 0.6 m Diameter	6-3	8.0	Small HDDT	Same as Above	Same as Above	Same as Above	6-4
4	Programmed 3 dB	Fixed Pointed 16° Beam	6-5	8.0	Small HDDT	Same as Above	Same as Above	Same as Above	6-6
5	Programmed 30 dB	Autotracked 1.0 m Diameter	6-7	8.0	Small HDDT	Same as Above	Same as Above	Same as Above	6-8
6	Fixed 115-km Radius Coverage	Autotracked 1.0 m Diameter	6-3	33	IRIG Std. 14-Track Miller Code	IR&T All All 4R+T	Full 2 x 3 Full Full	100% 100% 25% 40%	6-9
7	Programmed 30 dB	Fixed Pointed 7.9° Beam	6-10	33	Same as Above	Same as Above	Same as Above	Same as Above	6-11
8	Programmed 30 dB	Autotracked 1.0 m Diameter	6-7	33	Same as Above	Same as Above	Same as Above	Same as Above	6-12
9	Fixed 115-km Radius Coverage	Autotracked 1.8 m Diameter	6-3	106	See Text	All	Full	100%	----
10	Programmed 30 dB	Autotracked 1.2 m Diameter	6-7	106	See Text	All	Full	100%	----
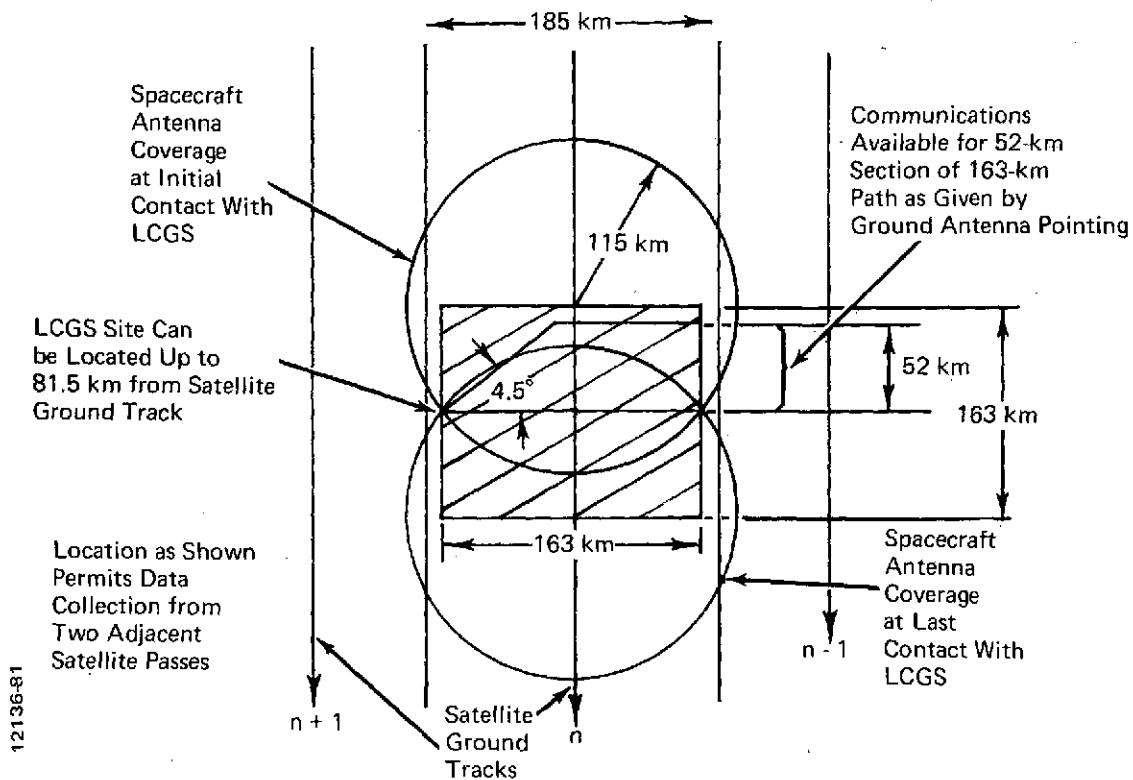
Figure 6-1 Communication Coverage, Fixed Spacecraft Antenna
and Fixed Pointable LCGS Antenna
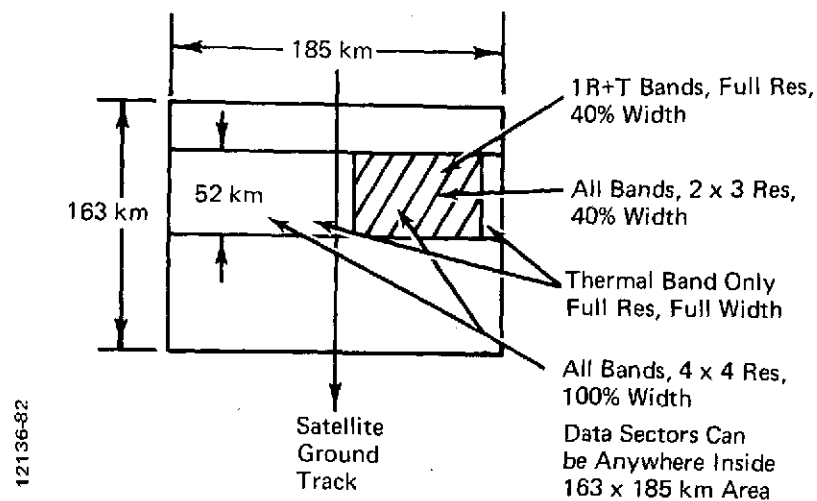
Figure 6-2 Data Acquisition for Candidate Concept 1
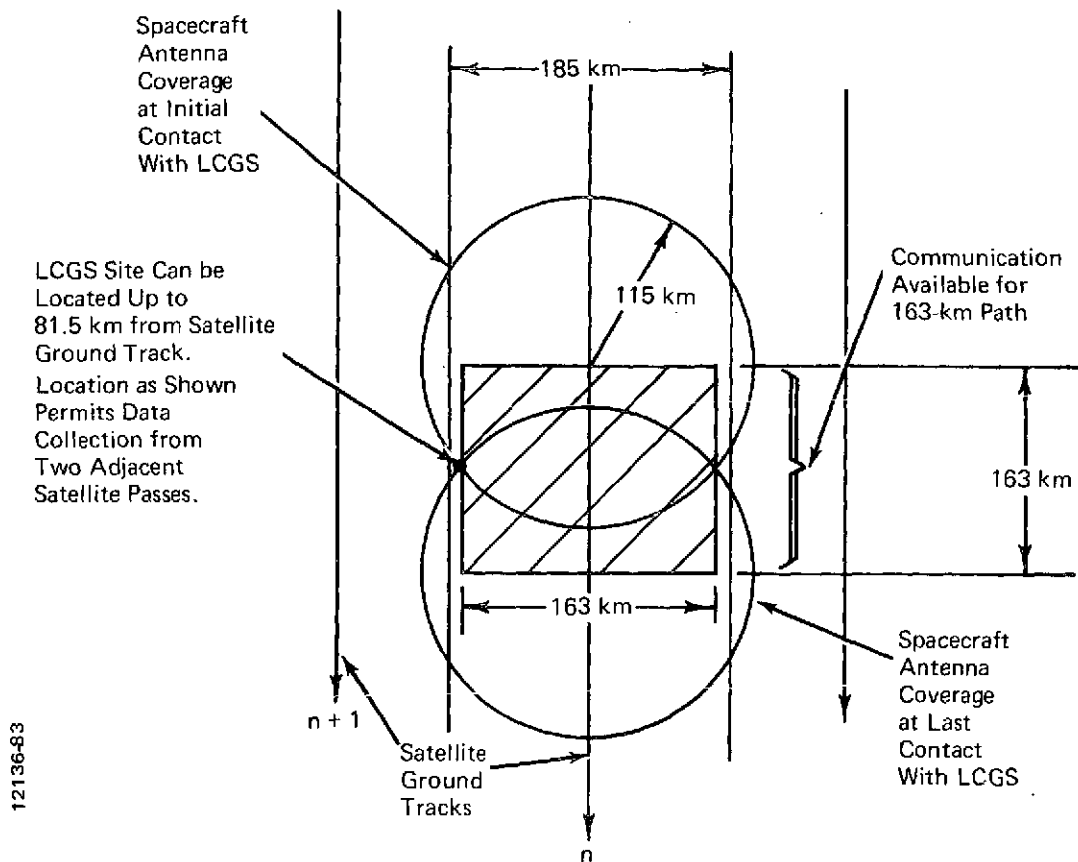
Figure 6-3   Communication Coverage, Fixed Spacecraft
Antenna and Tracked LCGS Antenna
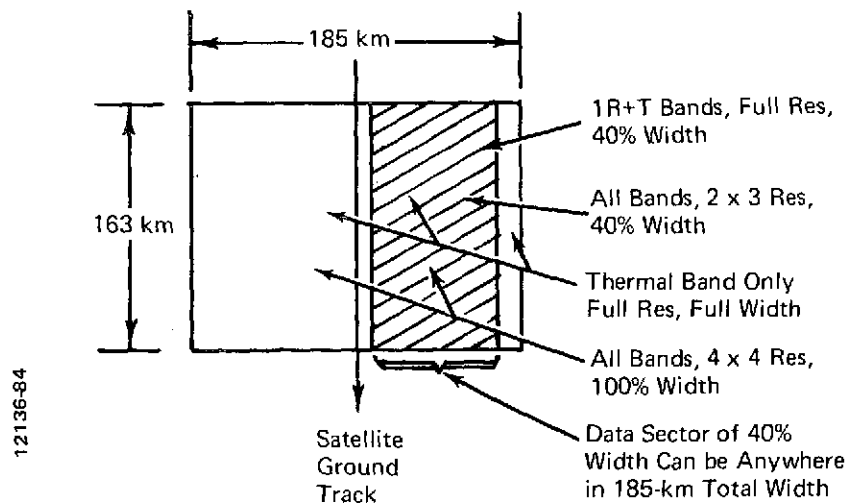
Figure 6-4   Data Acquisition for Candidate Concepts 2 and 3

500 km | ←— 185 km —→

182 km Min

16°

LCGS

Communication
Available for
Any 182-km
Section as
Given by LCGS
Antenna Pointing

12136-85

n + 2   n + 1   n   n - 1   n - 2

Satellite Ground Tracks
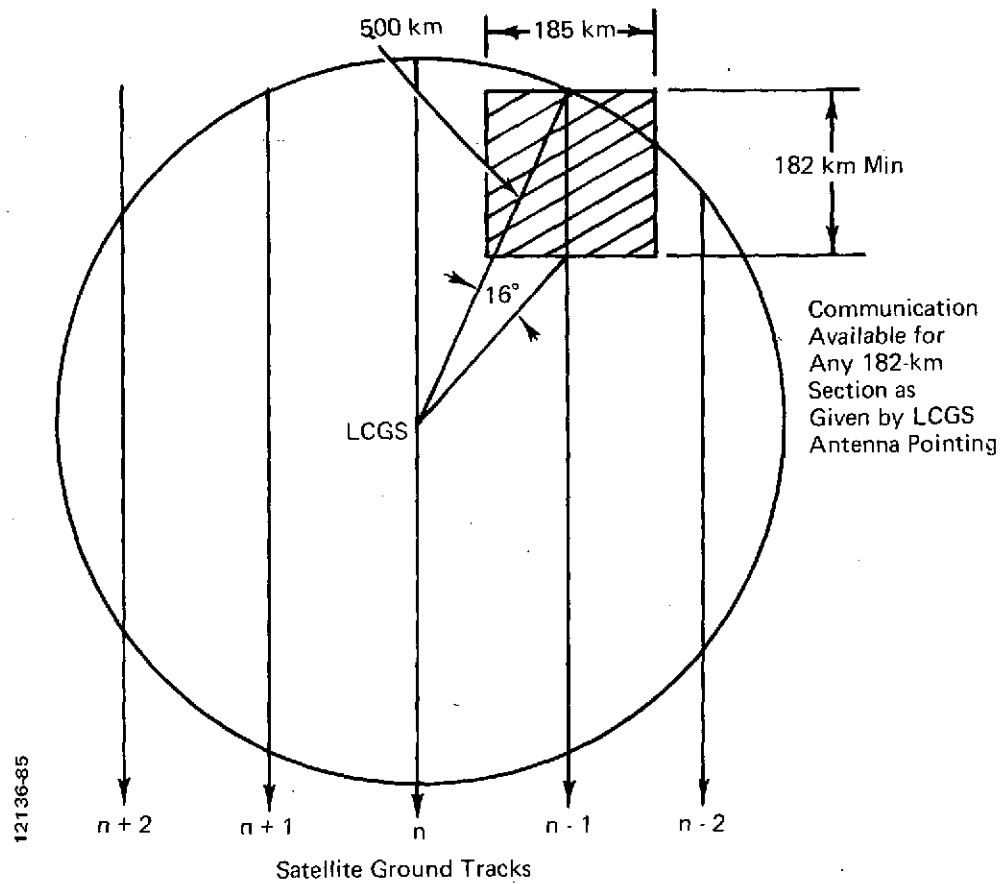
Figure 6-5 Communication Coverage, Programmed 30-dB
Spacecraft Antenna and Fixed-Pointed 16°. LCGS Antenna

←——— 185 km ———→

182 km
Min

1R+T Bands, Full Res,
40% Width

All Bands, 2 x 3 Res,
40% Width

All Bands, 4 x 4 Res,
100% Width

T Only, Full Res,
100% Width

12136-86

Satellite
Ground
Track
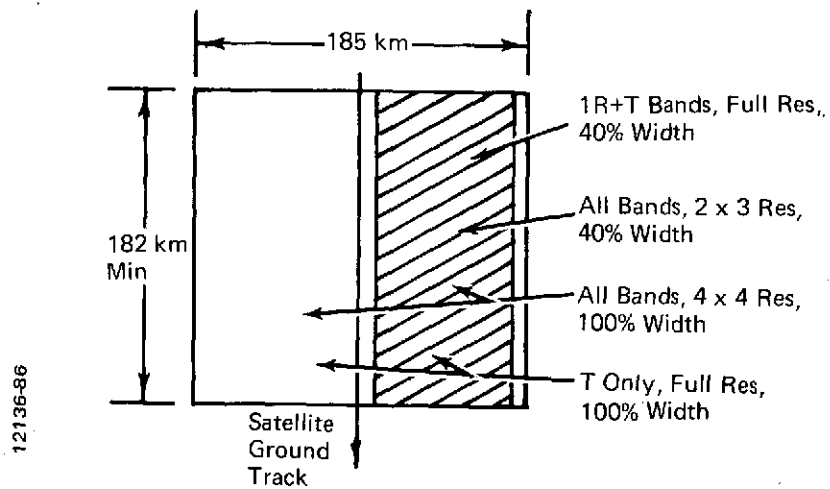
Figure 6-6 Data Acquisition for Candidate Concept 4

6-5 (II)
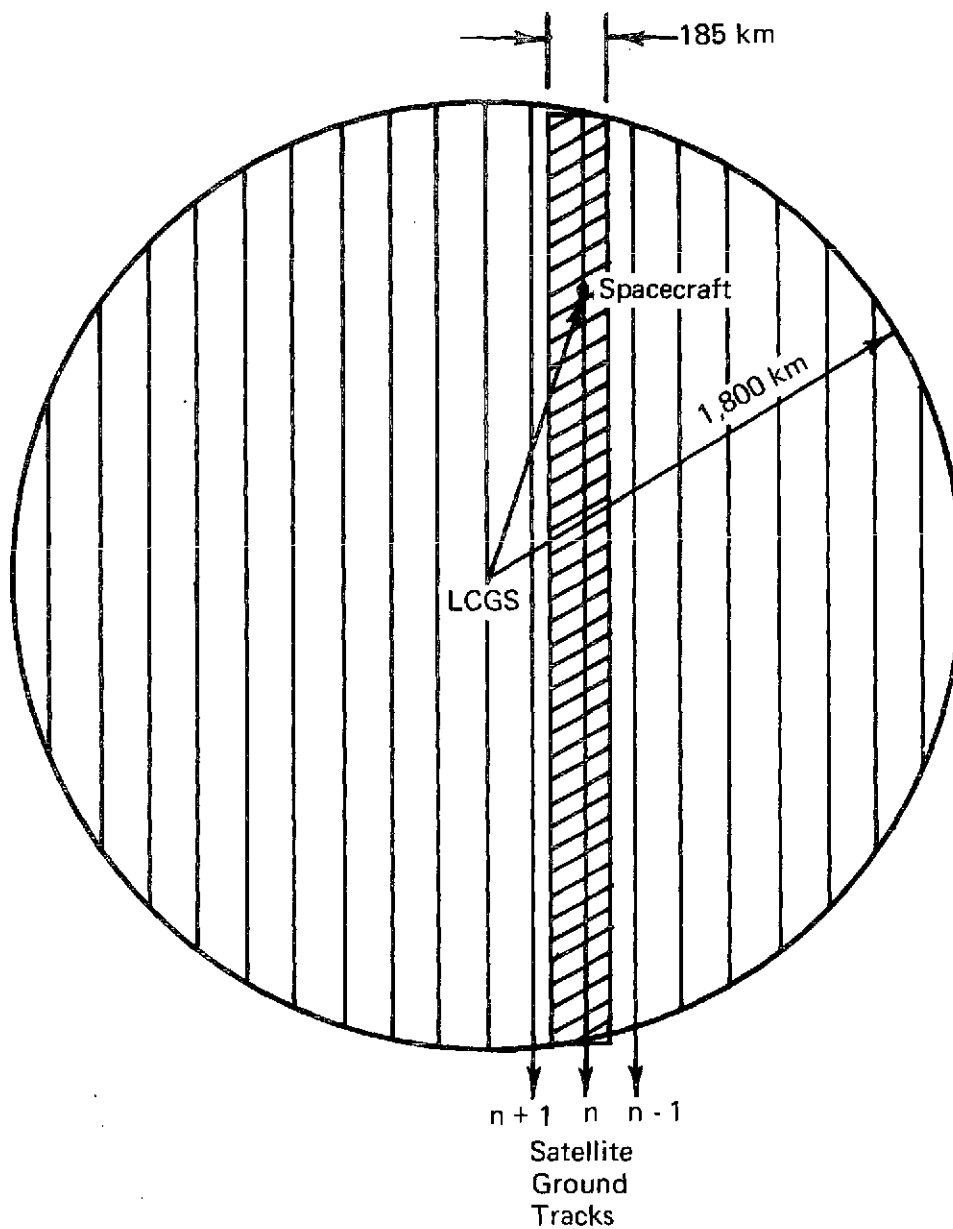
Figure 6-7 Communication Coverage, Programmed 30-dB
Spacecraft Antenna and Autotracked LCGS Antenna
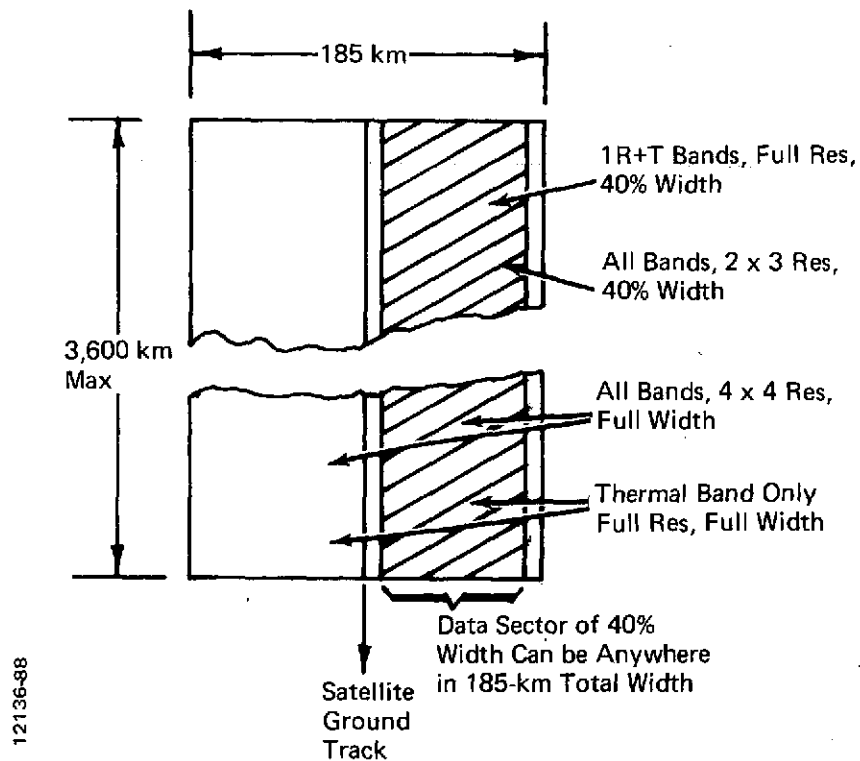
Figure 6-8 Data Acquisition for Candidate Concept 5
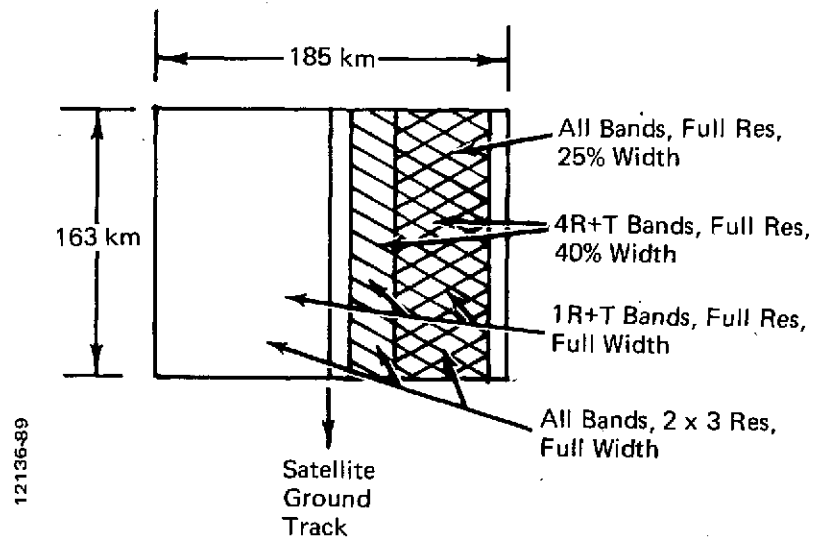
Figure 6-9 Data Acquisition for Candidate Concept 6
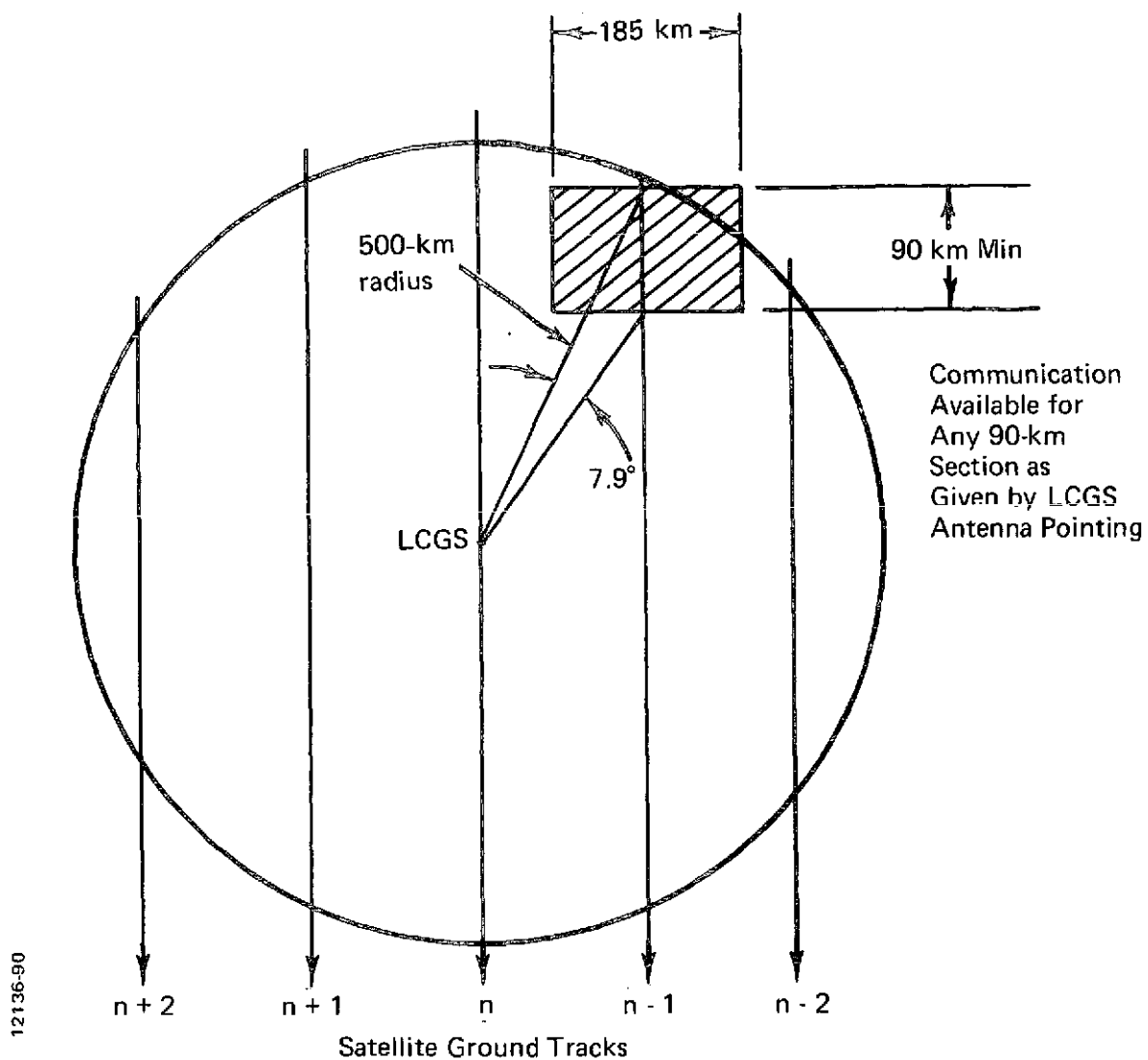
Figure 6-10 Communication Coverage, Programmed 30-dB Spacecraft
Antenna and Fixed-Pointed 7.9° LCGS Antenna

185 km

90 km
Min

1R+T Bands, Full Res, Full Width

All Bands, Full Res, 25% Width

All Bands, 2 x 3 Res, Full Width

4R+T Bands, Full Res, 40% Width

Satellite Ground Track
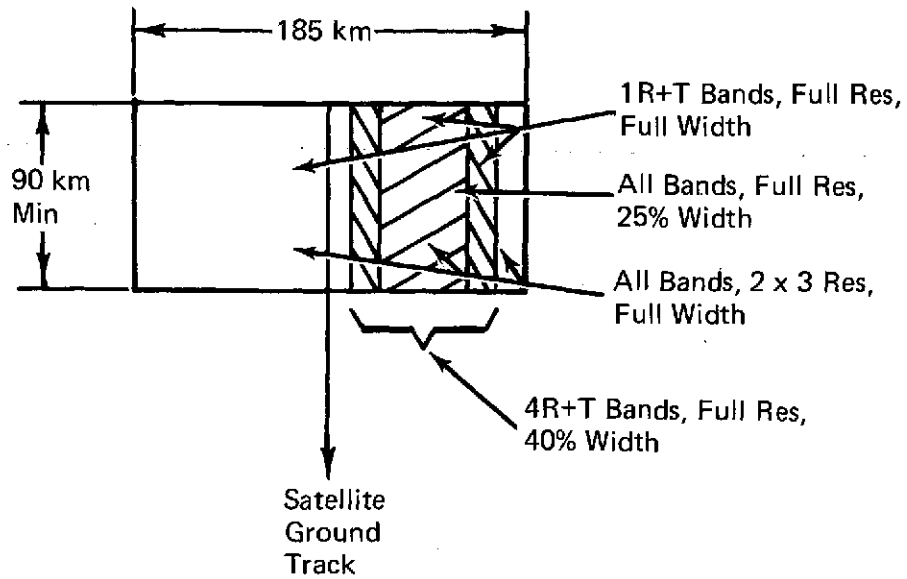
12136-91

Figure 6-11   Data Acquisition for Candidate Concept 7

185 km

3,600 km Max

1R+T Bands, Full Res, Full Width

All Bands, Full Res, 25% Width

All Bands, 2 x 3 Res, 100% Width

4R+T Bands, Full Res, 40% Width

12136-92
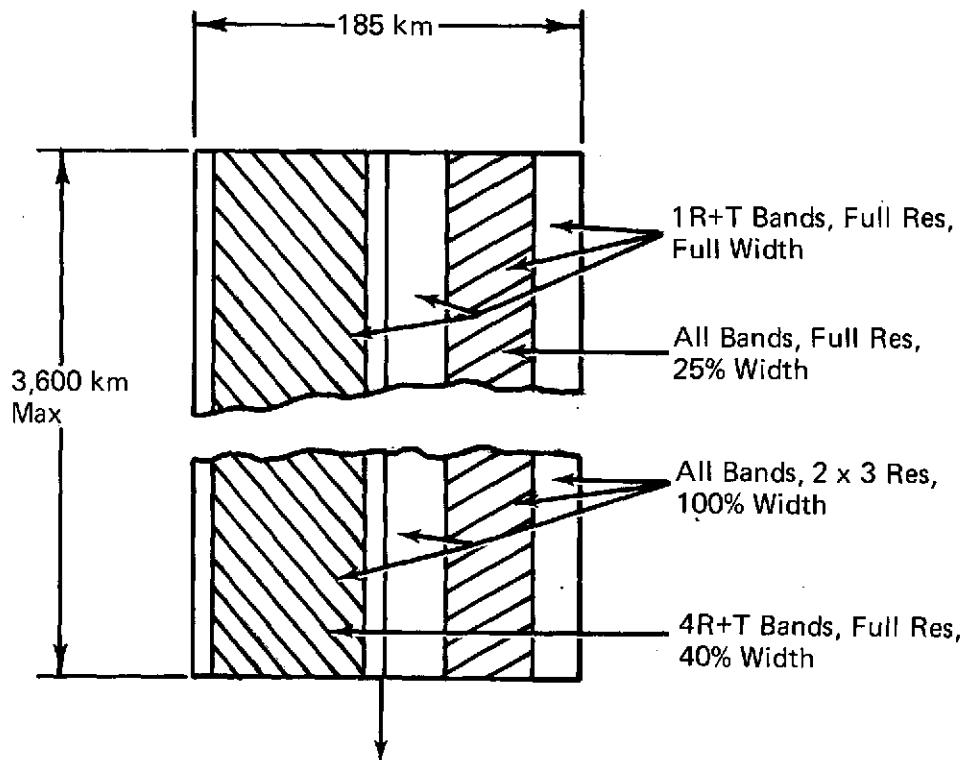
Figure 6-12   Data Acquisition for Candidate Concept 8

Analysis of the costs of these candidate concepts shows that only the Concepts 1 and 4 candidates certainly and perhaps Concept 2 are candidates for a really low-cost local user system. The other concepts, particularly 5, 7, and 8, are candidates for a modest cost regional data center. The LCGS described in Section 7 is based on Concepts 1 and 4 for which the ground system is identical except for ground antenna size. The LCGS could easily be changed to Concept 3 or 5 to gain their wider communications coverage by changing the ground antenna system to an autotrack antenna. The penalty, of course, is the added cost of the autotrack antenna.

In Concepts 1 through 5, the indicated data recorder is a small two-track HDDT. This unit can record at 8 Mbps for slightly longer than 30 seconds, which is adequate to record one 185 x 185 km scene per satellite pass over the station. If the longer record times indicated for Concept 5 as shown in Figure 6-7 are required, then a data recorder with more total capacity must be used. A recorder capable of meeting this latter need is an IRIG standard instrumentation recorder using four tracks in parallel. This type of recorder could record a total of 12 minutes at 8 Mbps to handle a full 3,600-km satellite pass directly overhead.

6.2 BASELINE SPACECRAFT LCGS DATA PROCESSORS

A functional block diagram of a spacecraft LCGS data processor that satisfies the requirements and constraints of Section 4.1 is shown in Figure 6-13. The interfaces to other subsystems are minimized with the thermal data being extracted at the input to the MOMS and the reflective data being extracted at the output from the MOMS.

By extracting thermal data at the input to MOMS, it is possible to perform thermal mapping at night without the MOMS being energized. This feature extends the operating time period of the system but at reduced power consumption levels. Control signals such as the scan reference pulse which are routed from the MSS instrument to MOMS must also be made available to the LCGS data processor. A data clock supplied from the MOMS, although not essential, will simplify the LCGS hardware. The LCGS data processor will thus utilize only signals which are already provided to the MOMS.

Data for the reflective bands must be calibrated for detector variation prior to processing, which combines samples to reduce geometric resolution and thereby data rate. This can be accomplished in the spacecraft LCGS data processor through a table look-up process. The calibration tables can be programmable from the ground via the EOS control center command link

to permit periodic calibration update. Calibration changes are expected to vary slowly so that this will not be burdensome. This onboard calibration would affect only the data to be transmitted to the LCGS. Data transmitted to the GCDS would remain uncalibrated and form the basis from which the calibration table update would be determined.

Because the LCGS data processor is required to be a multimode device that is switchable upon command, it is necessary that it be rather flexible. The optimum configuration can be obtained only after certain tradeoffs are performed. For example, a double-buffer approach could be utilized so that a single buffer is used to store alternate lines of data with the remaining lines being stored in a second buffer. While a line of data is being collected and stored in buffer B, the previously stored line is being read from buffer A and transmitted to the LCGS. With this approach, all arithmetic processes are performed at the output of the buffers and consequently at lower speeds. Control functions are simplified at the expense of increased buffer capability. It is, of course, possible to transmit the data in a very orderly and perhaps optimum sequence as far as the LCGS is concerned. All the reflective band data would therefore be routed through a buffer before being transmitted, whereas the thermal data would be transmitted as they are being collected.

An alternate approach and one in which the buffer size is minimized is the case where all data processing is performed prior to buffering the data. To further minimize the buffering requirements, some of the reflective band data are transmitted in real time. It is expected that the optimum system configuration is one which approaches this technique. Therefore, in the following discussions attempts are made to minimize the buffer size.

Simple arithmetic operations such as divide by two or four are easily accomplished within the spacecraft data processor. Operations such as divide by three, while possible, are best performed on the ground, although a divide by two operation could be performed within the spacecraft data processor with a multiplication by 2/3 being performed within the LCGS. Thus, in the case where data are to be compressed by two lines and three cells, it is recommended that the three successive samples from two adjacent lines be combined and seven bits rather than six be transmitted. Further arithmetic operations can then be performed within the LCGS.

6.2.1   Data Processor for 8-Mbps Link

As shown in Table 6-1, there are five candidate concepts which require a transmission data rate of 8 Mbps. For each of these concepts, it is necessary that the data processor be able to operate in four modes as shown below:

Mode	Bands	Resolution	Swath Width
1	IR+T	Full	40%
2	All	2 x 3	40%
3	T only	Full	100%
4	All	4 x 4	100%

The thermal data will be collected and formatted independently of MOMS for all modes and for Mode 3, MOMS may in fact be deenergized. In this mode, a data transmission rate of approximately 1.2 Mbps is adequate for transmission of the thermal band data.

In Mode 1 the data from three detectors of the eight-detector array of the selected reflective band and the thermal band are transmitted in real time while the remaining data are stored. After scanning approximately 40% of the swath, the data collection process ceases and data from the other five detectors are read from the buffer and transmitted. When operating in Mode 1, every 3.4-μsec (sample period) a 30-bit word (6 bits x 5 channels) is presented to the buffer.

When operating in Mode 2, the data processor compresses the data by adding three adjacent samples from two adjacent detectors and divides by four to produce a 7-bit word. This 7-bit word is transmitted to the LCGS where it is multiplied by 2/3 through a table look-up approach. It is recommended that tradeoffs be performed to determine whether it is better to perform the table look-up operation in the spacecraft so that 6 rather than 7-bit words can be transmitted. In Mode 2 a 112-bit word (7 bits x 4 bands x 4 channels/band) is formed every 10.2 μsec.

In the case of Mode 4 operation, four adjacent samples from each of four adjacent detectors are combined. The result is divided by 16 and transmitted in real time without buffering.

Again certain tradeoffs should be performed in the detailed system design phase to select the memory word length most compatible with the above buffer requirements. The buffer size will be about 100K bits. The speed, word length, and size requirements are compatible with both a solid-state (MOS serial shift register or RAM) and a plated wire memory.

6.2.2 Data Processor for 33-Mbps Link

Concepts 6, 7, and 8 in Table 6-1 have a common data rate of 33 Mbps. In all cases the data processor modes of operation are as described below:

Mode	Bands	Resolution	Swath Width
1	IR+T	Full	100%
2	All	2 x 3	100%
3	All	Full	25%
4	4+T	Full	40%

As described in the previous section, the thermal data for all modes are best collected and transmitted as shown in Figure 6-13. Buffering is not required for operation in Modes 1 and 2 and, in fact, the required data rate is well below the 33 Mbps as can be seen from Figure 4-16. When operating in Mode 3, the data collected from the thermal band and one reflective band are transmitted in real time. By storing the data from the other five bands, they can be transmitted well within the 33-Mbps rate after the data collection process is terminated. A similar approach is employed in Mode 4. Data from three bands are stored and transmitted after real-time transmission ceases. A buffer of about 60K bits is required with the input rates being less severe than for the 8-Mbps transmission rate case.

6.2.3 Data Processor for 106-Mbps Link

For Concepts 9 and 10 where the data rate is 106 Mbps, the MOMS output can be transmitted directly.
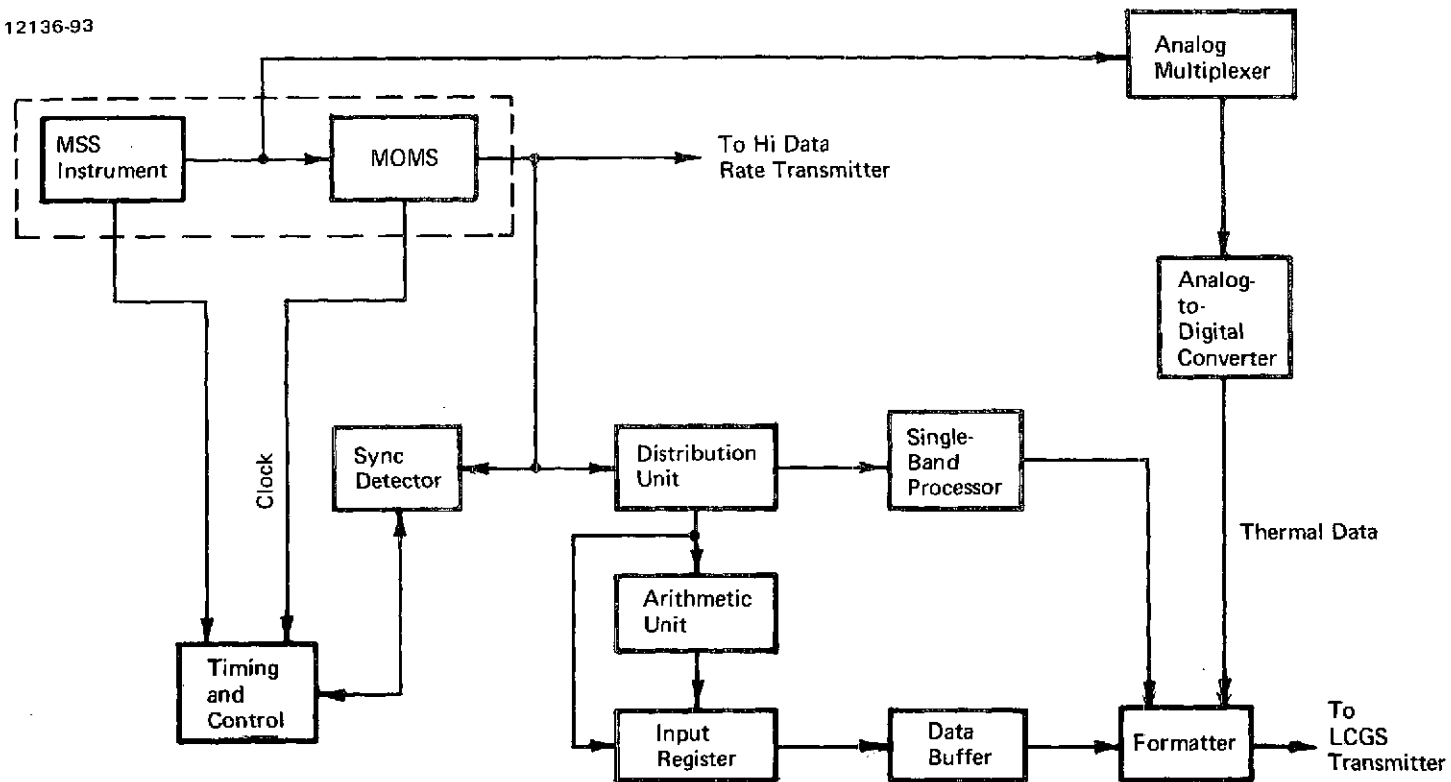
Figure 6-13 Baseline Spacecraft LCGS Data Processing

SECTION 7

LOW-COST GROUND STATION (LCGS)

The concept of the LCGS is shown in the functional diagram of Figure 7-1. This section describes the LCGS functions, hardware and software design, and operations in subsections corresponding to each of the major hardware subsystems. These subsystems are: (1) spacecraft data formatter, (2) spacecraft LCGS data transmission subsystem, (3) ground LCGS data receiving subsystem, and (4) LCGS data processing subsystem. The LCGS described in this section is designed to handle data from an EOS linear multispectral scanner. The impact of receiving data from other potential EOS scanners, particularly the conical scan MSS, is discussed in Section 8.

7.1 LCGS SYSTEM

The LCGS system is based on the candidate Concept 1 described in Section 6. The system described herein however, is equally applicable to candidate Concept 4, which having a program-steered spacecraft antenna, has a broader beam fixed-pointed LCGS antenna to yield more data per satellite pass as shown in Section 6.

The operational concept of the LCGS requires cooperation between the EOS control center and the LCGS operators. Desiring data from a specific area, the LCGS operator requests that the control center command the spacecraft to transmit data in a requested format during a future overflight. Assuming there is no scheduled conflict with other LCGS units, the control center provides the LCGS operator with antenna pointing data and the predicted time of overflight. The LCGS operator positions the fixed-pointed LCGS antenna as instructed and awaits spacecraft overflight. The ground antenna is then positioned as shown in Figure 7-2 so that the spacecraft will pass through the ground antenna beam at the time when the spacecraft MSS can scan the desired area. The along-track distance x over which data can be transmitted is dictated by the ground antenna beamwidth as shown in Figure 7-2. The across-track width of the data collection area is dictated by the 8.0-Mbps data transmission and recording rate limits and the combination of spectral bands and resolution requested in advance. Figure 7-3 shows the data area for four selected combinations of bands and resolution. The 40% swath width of data for the two modes shown can be prearranged to be any 40% segment of the total 185-km swath width. In the along-track direction the 52-km distance can be located anywhere along the 163-km spacecraft traverse during which time the spacecraft antenna coverage includes the LCGS site as shown in Figure 7-4. This figure also shows that the LCGS could be sited to yield coverage from two adjacent satellite passes.

Imaging Sensor

Multispectral Scanner – MSS

High Res Pointable Imager – HRPI

On-Bd Processor

Selective Data Processing Functions

Other Data Processing Functions

Xmtrs

Directive – Narrow-Band Function

Wide-Band Video Comm Function

Command System

Other Command Functions

Commands for Selective and Directive Functions

Satellite Functions

Ground Functions

EOS Control Cntr

Command Encoding and Transmission

Satellite Tracking

Low Cost Ground Station

Data Record and Playback Function

Antenna and Pointing Function

Data Processing Function

Narrow-Band Data Receiver Function

Wide-Band Data to National - Regional Sites

Data Requests

Ephemeris Data

Prerecorded Data from Regional or National Stations

LCGS Products to Users

12136-94

Figure 7-1 Functional Diagram: Concept for Low Cost EOS Ground Station
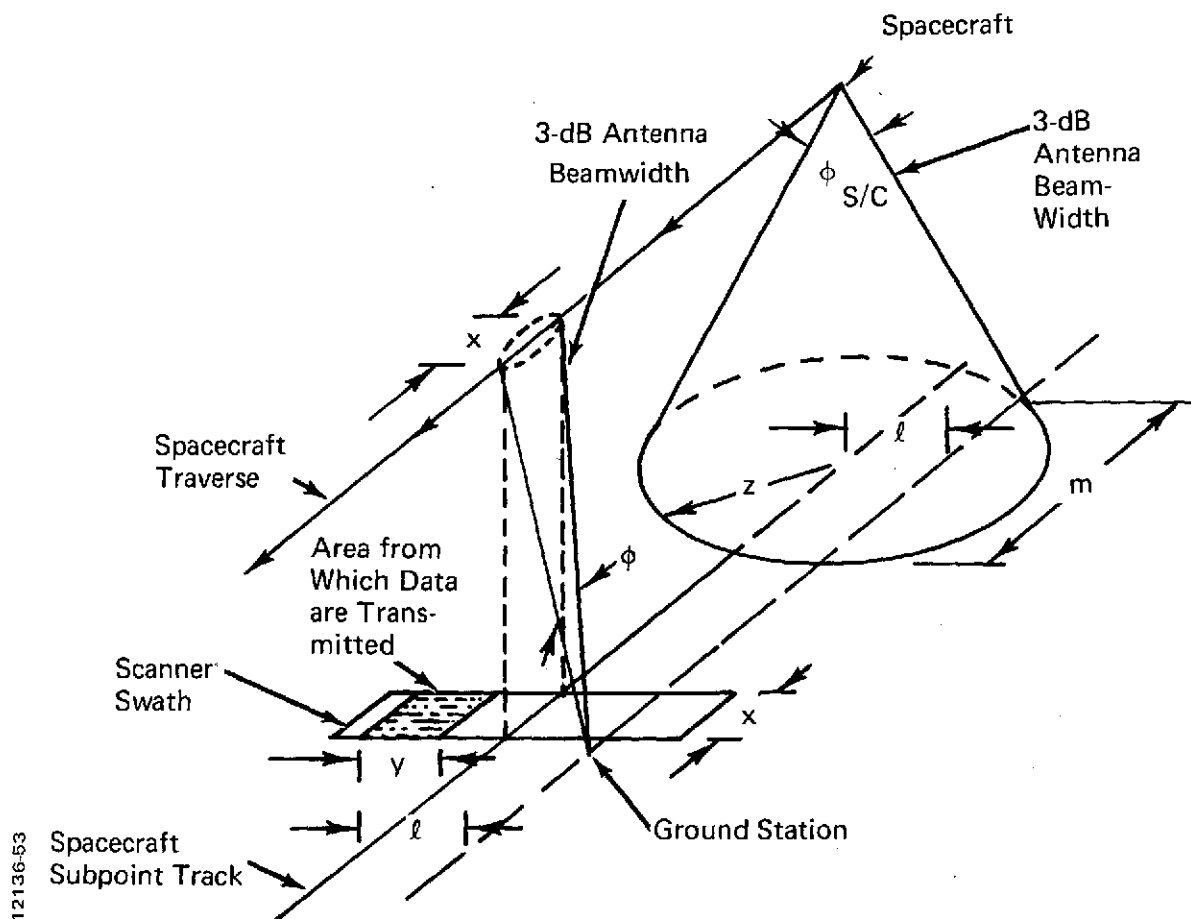
Figure 7-2 Ground Station with Fixed-Pointable Antenna
Awaiting Passage of Spacecraft
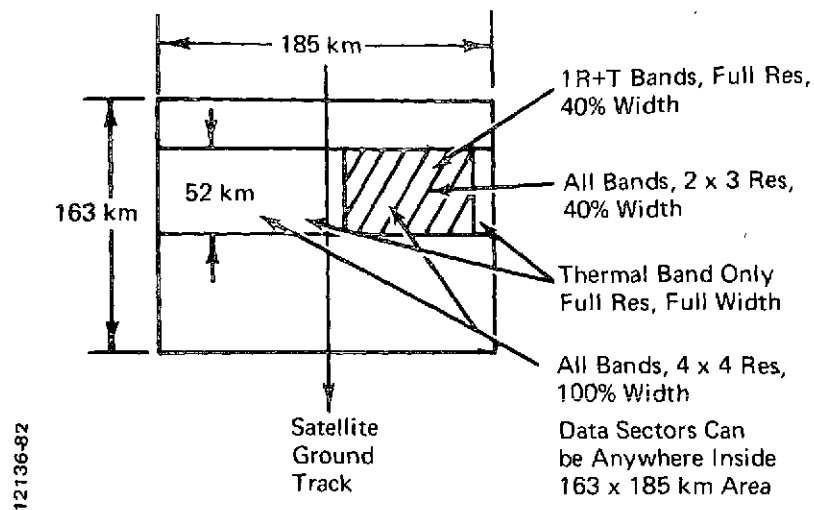
Figure 7-3 Data Acquisition for Coordinate Concept 1
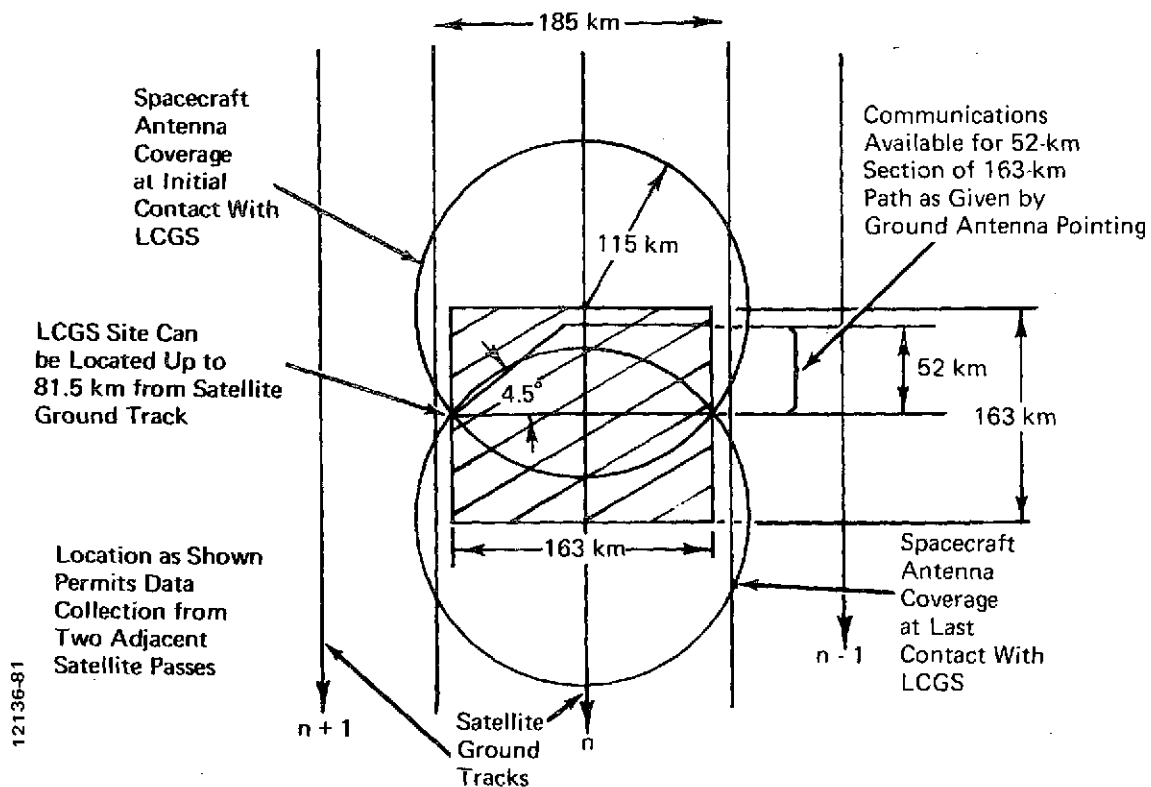
Figure 7-4 Communication Coverage, Fixed Spacecraft Antenna
and Fixed-Pointable LCGS Antenna

As the satellite passes through the ground antenna beam, data are re-corded in the LCGS at a rate of 8.0 Mbps for a duration of about 8 seconds. Subsequent playback of this data for processing in the LCGS is at a substan-tially reduced data rate, which is prescribed by the specific data processing operations performed. This reduced rate processing is possible because only one image frame per satellite pass is available. It permits all data pro-cessing operations to be performed in a minicomputer-based subsystem.

If the spacecraft has a program-steered antenna, then somewhat better coverage is possible as shown in Figures 7-5 and 7-6. The operational con-cept remains the same as shown in Figure 7-2 where the LCGS antenna is fixed-pointable, pointed to yield the desired along-track coverage, and re-ceives data when the spacecraft flies through the beam. The program-steered spacecraft antenna would have a 9° beam. The direction of initial pointing and the pointing program would be predetermined by the EOS control center when the LCGS and data collection sites have been agreed upon.

As a result of the high-gain spacecraft antenna, the maximum range of coverage is a 500-km circle (on the ground) about the LCGS site as shown in Figure 7-5. The data gathering area would be extended somewhat laterally by offset pointing the sensor. In addition to the larger communication co-verage area, the increased spacecraft antenna gain permits broadening the LCGS antenna to lengthen the data coverage in a single satellite overflight as shown in Figure 7-6. Comparison of Figures 7-4 and 7-6 shows that the along-track coverage increases from 52 km to 182 km, thereby permitting collection of data over a 185 x 182 km scene, or approximately the equivalent of one full scene as distributed by the General Central Data Processing (GCDP) facility.

With reference to Figure 7-5, an orbit can be chosen so that each day the satellite ground track shifts one track. This means that, for the cover-age shown, 5 days would be required to permit access to the area shown. Orbits are possible, and should be considered, for which this daily shift is more than one track. For example, if an orbit with two-track daily shift were chosen, then, with the lateral offset capability of the MSS, the LCGS could have access to the entire area shown in just 2 days. This would in-crease the timeliness capability of the LCGS and permit more flexibility for a mobile LCGS. Possible orbits with various properties applicable to this choice are discussed in Appendix B.
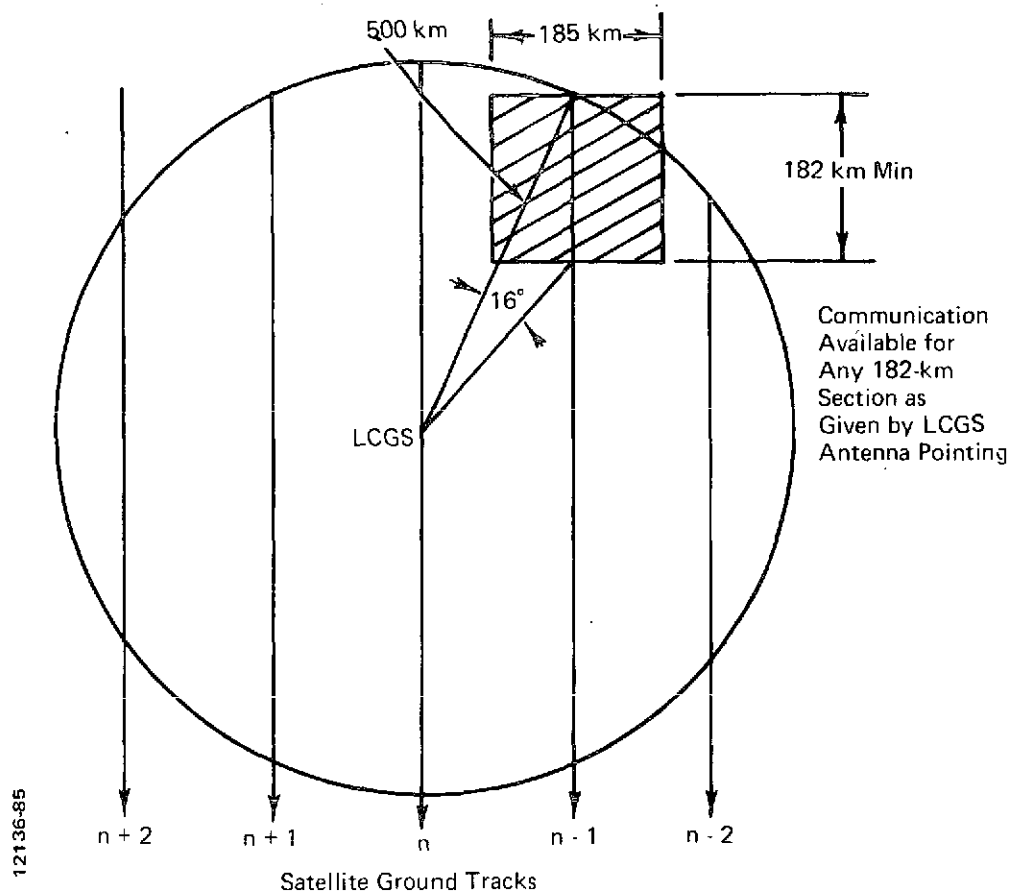
Figure 7-5 Communication Coverage, Programmed 30-dB
Spacecraft Antenna and Fixed-Pointed 16° LCGS Antenna
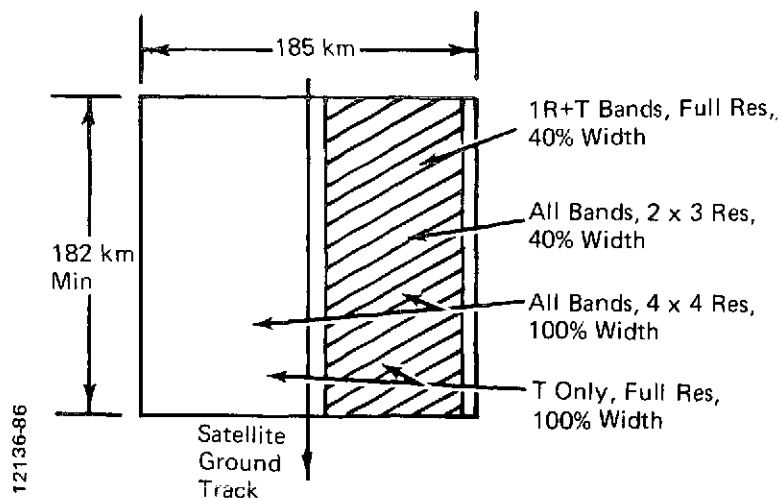
Figure 7-6 Data Acquisition for Candidate Concept 4

In addition to processing data received directly from the satellite as described above, the LCGS can process data received from the GCDP. Data could be received either in the form of computer-compatible tapes (CCTs) or in a LCGS-compatible HDDT format. The LCGS therefore can provide an interactive data processing capability for data received from either source. A mobile or transportable LCGS system therefore could be scheduled to move into an area, receive and process the desired real-time data, process a backlog of data collected from the GCDP, and move on to another area.

7.2 LCGS DATA RECEIVING SUBSYSTEM

The LCGS data receiving subsystem is shown in Figure 7-7. It operates at a frequency of 8.5 GHz and the received data rate is 8.0 Mbps. Output from the receiving subsystem is 8.0-Mbps data in Non-Return to Zero (NRZ) format and a data clock. The data and clock outputs are interfaced to the data recorder in the data processing subsystem.

Physically, the receiving subsystem consists of two assemblies: (1) the antenna mount, which includes the antenna, preamplifier electronics, and down converter, and (2) a rack-mounting assembly containing the IF amplifier, demodulator, bit synchronizer, and power supplies. The antenna mount assembly weighs 64 kg and the rack mounting assembly weighs 9 kg. The complete receiving subsystem requires a total of 300 W of prime power. Except for the LCGS antenna, the LCGS receiving subsystem is identical for either a fixed-pointable or program-steered spacecraft antenna.

It was computed in Section 3.3.1 that the antenna must be sited and positioned to within a sighting error of $\pm 0.18°$. In allocating this error between ground station location and bearing uncertainties, a siting error of 1 km was allocated. This position uncertainty is approximately 30 sec of arc in latitude and longitude at the equator. This accuracy can be established at many locations within the continental United States by the use of a US Geological Survey map. At other locations, both latitude and longitude can be determined to 15 sec of arc or better by star sighting with an engineer's transit. An accurate chronometer referenced to a precise time standard must be carried to provide a local time to 1 sec to determine longitude.

7-8 (II)

Antenna Dish and Feed

Beamwidth = 4.5°
Gain ≈ 31 dB
Dia ≈ 0.55 m
Circularly Polarized
Horn Feed
Weight ≈ 5.4 kg

Temperature Controlled Preamp and Downconverter
Package, Mounted on Antenna Mount

Weight ≈3.6 kg
Volume ≈5250 cm3

Hard Limiting at 0 dBm Input
Discriminator Linear
Range ± 3 MHz

PCM
Data

Tunnel
Diode
Preamplifier

Image
Rejection
Notch
Filter

Double
Balanced
Mixer

IF
Preampli
fier
70 MHz

IF
Amplifier
70 MHz

Limiter/
Discriminator
and Video
Amplifier

Bit
Synchronizer
8 Mbps

Data
Clock

Noise Figure 4.6 dB
Gain 17 dB

Rejection
> 20 dB

Noise Figure 1.5 dB
Gain 15 dB
Bandwidth 15 MHz

Minimum Received
Signal -86 dBm
Frequency Modulation
at 8 Mbps, 5.6 MHz
Peak-to-Peak Deviation

Elevation
Over
Azimuth
Mount

Local
Oscillator

Conversion Loss 7.5 dB

Stability
1 pt in 10^5

3 dB Bandwidth 8 MHz
Gain 70 dB
Either AGC or Log IF
to Provide Signal Strength
Indication

Mounting Panel for:
Signal Strength Meter
IF Amplifier and Limiter/
Discriminator
Power Distribution

Leveling to ± 20 sec
Axes Orthogonality ± 20 sec
Position Repeatability and
Readout to ± 0.025°
Antenna and Telescope
Boresighted to ± 0.04°
Weight ≈ 55 kg

Figure 7-7   Telemetry Receiving Station with Fixed-Pointable Antenna

7.3 LCGS DATA PROCESSING SUBSYSTEM

The LCGS data processing subsystem is designed to be an interactive data processing unit enabling local users to take an active role in processing, evaluation, and utilization of data received from the EOS multispectral scanner instrument. In its primary operation mode, this subsystem receives data from the LCGS receiving subsystem as an 8.0-Mbps serial data stream in NRZ form and a data clock. In a secondary mode of operation, data are received from the GCDP in the form of two-track HDDT or nine-track CCT magnetic tapes.

7.3.1 Data Processing Functions

The LCGS, as shown in Figure 7-8, is configured to perform the following functions:

- Data recording and playback.
- Data demultiplexing.
- Interactive display.
- Classification processing.
- Geometric correction.
- Radiometric correction.
- Aperture correction.
- Film recording.

These functions are described in Section 5.1.

The principal processing functions of the LCGS are data demultiplexing, radiometric correction, and classification processing. Geometric and aperture correction functions are auxiliary LCGS functions, which would be applied only in special cases as required by the local user. In accordance with this designation of functions, separate software routines are provided for the principal function and each auxiliary function, which are used separately and selectively as required by the local user.

7.3.2 Data Processing Subsystem Description

The basic LCGS data processing subsystem is shown in block diagram form in Figure 7-8 along with two optional components shown in dotted lines — the 1,024-line black and white display and the CCT units. The optional units

Direct Data Input from Receiving Subsystem

NRZ Data

Clock

Data Encoder

Time

Data Recorder (2 Track)

Data Recorder Interface

HDDT

Alternate Data Input from GCDP Facility

CCT

CCT Unit (Option)

CCT

Data for Processing in User Data Center

Disc Memory 1.25 Mega-Words

CCT Controller (Option)

Film Recorder

Color or Black and White 102 x 107 cm Frames

Computer Data Bus

Display Refresh Memory

Scan Converter (Option)

CPU + Extended Arithmetic Unit

Core Memory 16 K Words

Manual Input Satellite Intercept Time

Digital Clock/ Programmer

Control Panel and Cursor Controller

Tele-Typewriter

Color CRT Display

B&W CRT Display (Option)

Hr, Min, Sec Display

256 x 256 Resolution 6 Bits/Pixel (64 Colors)

1,024 TV Line Display

Operator Interface

Figure 7-8   LCGS Data Processing Subsystem Block Diagram

are discussed in Section 7.3.5. The basic subsystem consists of a mini-computer with peripherals for data input, interactive operator communications, hard copy output, and computation capability to perform the basic LCGS functions.
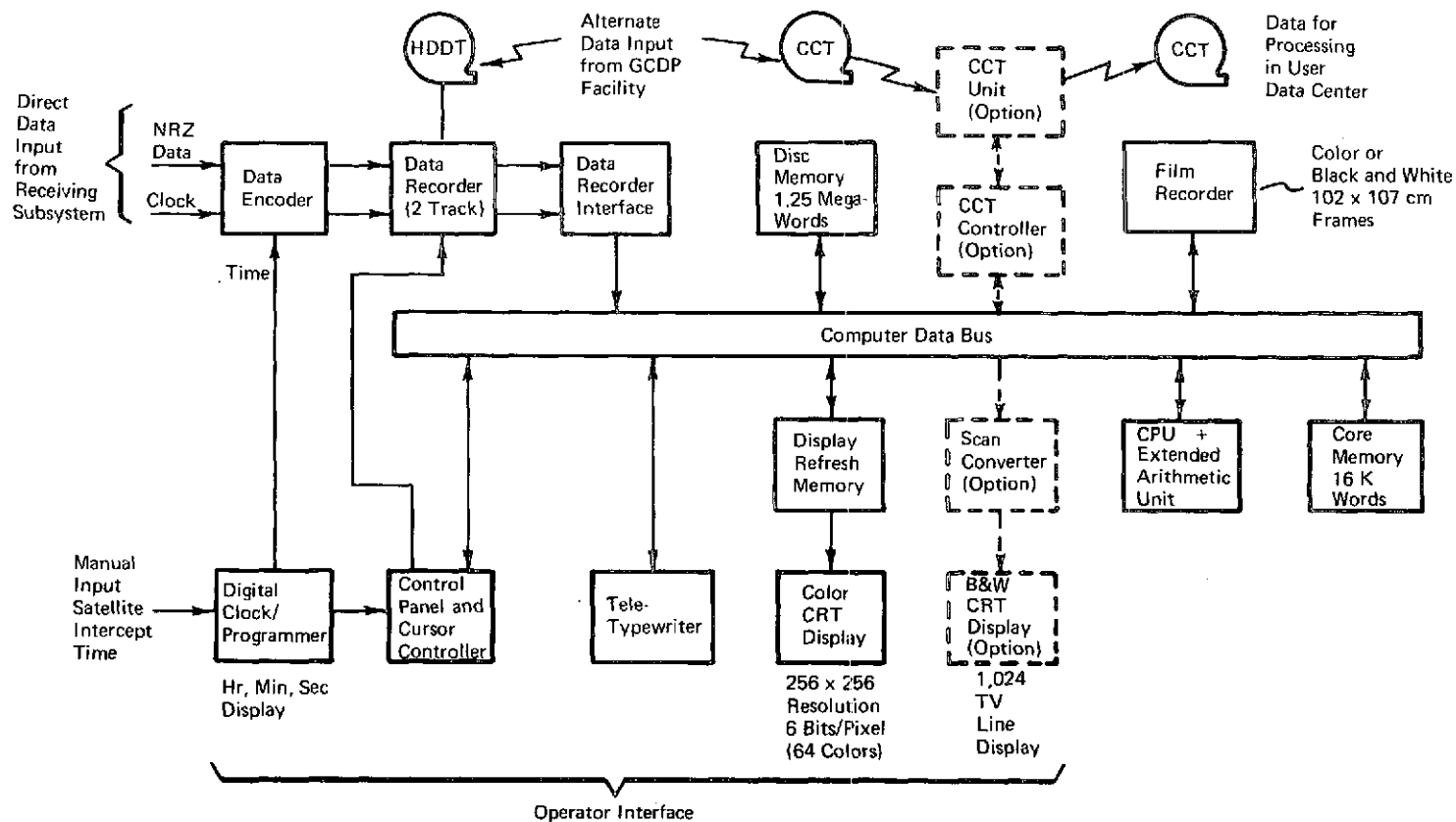
In the basic mode of operation, data are inputted to the data encoder from the receiving subsystem as an 8.0-Mbps serial NRZ data stream and a data clock. In the data encoder, local time from the LCGS digital clock/programmer is multiplexed with the 8.0-Mb data stream. The resulting data are then multiplexed to two tracks, framed, frame synchronization words added, and encoded for HDDT recording.

The data recorder is a non-IRIG standard instrumentation recorder capable of recording over 5 Mbps per track for 30 sec at a record speed in excess of 300 inches per second (ips). Playback speed and data rate are very much lower than record and are dictated by the data processing requirement.

Operator interaction with the subsystem is through the teletypewriter (TTY), control panel, and cursor controller for operator inputs, and through the color CRT display and TTY for system outputs to the operator.

The color CRT display presents an image of 256 scan lines with each line containing 256 six-bit image data elements (pixels). The display re-fresh memory accepts data from the computer at a rate given by the type of processing performed on the data. The memory stores one complete 256-line frame of data and outputs it to the CRT display at 60 frames per second to present a flicker-free image on the screen. As data are input to the re-fresh memory, each new line is displayed at the top of the CRT with older lines moving down the screen to accommodate the new line. Data input can be halted at any point, and the image will remain displayed until data input is again started at which time the "moving window" operation will resume. The assignment of colors to the 64 words corresponding to the 6-bit words stored in the memory is programmable without modifying the words stored in the refresh memory. The operator therefore can specify various color encodings and observe the effect on the display in real time as the encoding of the entire screen will be changed in one TV frame time, 1/60 of a second. This feature is of particular value when "level slicing" and assigning colors to various levels to enhance observation of subtle data level changes.

A seventh bit is included in each word in the refresh memory for storing computer-generated graphics, which include cursor symbol overwrite and alphanumeric overwrite characters from a hardware character generator. The CRT display is a 30.5 cm (12 in.) TV-like monitor.

The cursor controller is an eight-axis switch, which permits the operator to position a cursor indicator to any location of the CRT screen. At any location, the operator can designate the position of the cursor to the computer and cause either a rectangular or essentially free-form symbol to be overwritten on the data displayed. The essential difference is that "free form" symbols require more processing time than rectangular symbols. The location of these symbols may be designated for storage in computer memory, thereby permitting the operator to designate data areas to be remembered by the computer for later processing. This capability forms the basis for data editing and training sample extraction required for classification processing of multispectral image data.

The film recorder is a critical cost element of the LCGS. The unit presently considered best for the LCGS is a color precision CRT/framing camera unit which will handle the full 2,400-line resolution of the LCGS data output. Its present ROM cost of about $40,000 is considered too high for the LCGS need. It would appear that a simple one-frame drum scan color recorder could be made for less money; however, none is presently available (see Table 5-3). The precision CRT/camera unit included in the LCGS has a maximum output rate of 1,260 sec/frame on 10.2 x 12.7 cm (4 x 5 in.) color film. This film recorder can present the data in hard copy as defined in Table 5-2.

The minicomputer presently considered for the LCGS is a Digital Equipment Corporation PDP-11. In the EOS time frame, there will likely be some more advanced units available, perhaps at less cost. Evaluation of such a change, however, must consider the cost of software changes, as most of the routines required will be available for the PDP-11 computer.

7.3.3   Data Processing Subsystem Operation

The data processing subsystem performs operations in support of data reception as well as its primary operations of data processing. This section briefly describes these operations.

Should it be necessary to determine the LCGS siting location via star sighting with an engineer's transit, a local time source accurate to 1 sec is required. The digital clock in the data processing subsystem supports this function.

When the LCGS has been sited and is awaiting overflight of the space-craft, the data recorder must be actuated at precisely the time at which the spacecraft enters the position where it can collect desired data. Proper allowance must be made for the start time of the recorder. The data processing subsystem digital clock/programmer controls the data recorder during this time. The operator manually enters the predicted spacecraft intercept time as designated by the EOS control center.

Once data have been received and recorded, the LCGS proceeds to perform the data processing functions previously listed. Table 7-1 is an outline of the operator and computer operations during the classification processing function.

Extraction of training data, as described in Table 7-1, can require a widely variable amount of time, depending upon the geographic distribution of the training sets within the scene. An average time of between 10 and 30 minutes is estimated for 10 training sets in one scene.

After the training data have been located and stored in memory, i.e., after completion of the above training data extraction, the calculation of classification processing coefficients is estimated to require approximately 15 minutes.

Given the classification processing coefficients calculated above, it is estimated that the classification processing will require approximately 5 milliseconds (msec) per pixel which is about 12 sec per scan line.

At the above rates, a scene of 52-km length along track would require about 2 hours for classification if all spectral bands are used, and a scene of 182 km would require about 5 1/2 hours. If all spectral bands were not used, the times would be proportionally lower.

Higher throughput during actual classification processing could be achieved with an optional hardwired classification processor.

7.3.4 Data Processing Subsystem Physical Description

The physical configuration of the data processing subsystem is shown in Figure 7-9. The two racks shown in the center contain all electronics for the basic LCGS except the film recorder and TTY shown and the antenna and antenna mount assembly described in Section 7.2. The rack assembly shown is 1.82 m high, 2.2 m wide, and 0.75 m deep. Total weight of the complete LCGS data processing subsystem is about 910 kg. Power requirements for the basic data subsystem is 115 volts ± 10%, 60 ± 1 Hertz, 6,000 watts at 0.8 power factor.

IF and Bit Synchronizer	Data Recorder		Color Film Recorder
Digital Clock/Programmer			
Color CRT Display	Computer		
Control Panel	Data Recorder Encoder and Interface		
Table			
Display Refresh Memory	Disc Memory		
Power-Supply	Power Supply		
Blower	Blower		

Teletypewriter
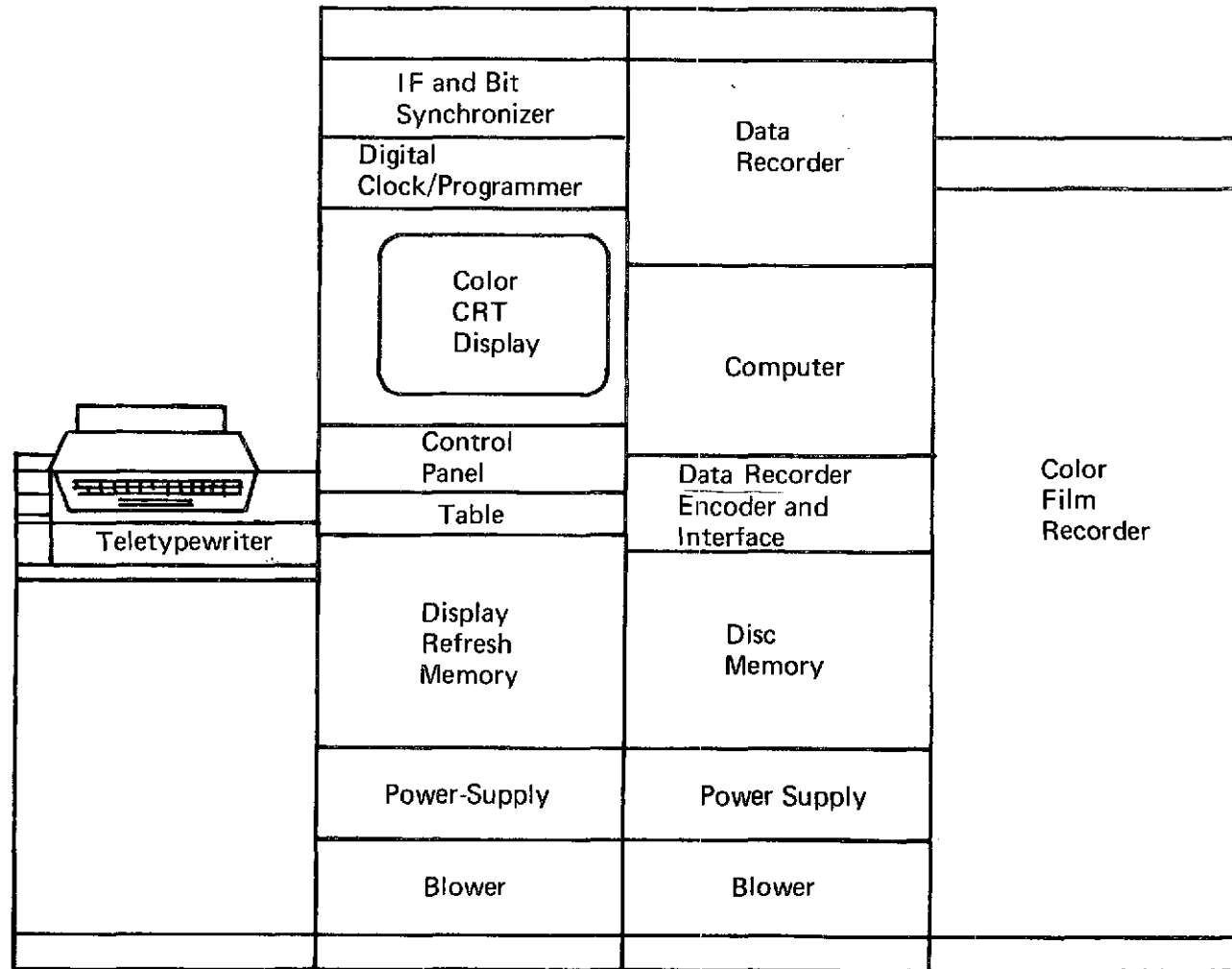
Figure 7-9 LCGS Data Processing Subsystem - Physical Configuration

Table 7-1

Outline of Classification Processing

I. Extraction of Training Data

	Step	Executed By
1.	Instruct computer via TTY to load TRAINING routine into core.	Operator
2.	Load TRAINING routine into core.	Computer
3.	Enter data resolution and swath width to computer via TTY.	Operator
4.	Locate data collection area in map.	Operator
5.	Locate training data sites on map.	Operator
6.	Calculate rough location of training sites on input data tape in terms of time of recording and segment of data swath.	Operator
7.	Enter rough locations of training sites into computer via TTY.	Operator
8.	Enter via TTY the spectral band to be displayed and start data tape recorder in slow playback mode.	Operator
9.	Search for time of first training site.	Computer
10.	At time of first training site, begin inputting data to disc.	Computer
11.	When sufficient data have been input to disc, begin selected transfer to color display.	Computer
	(Steps 10 and 11 constitute the data demultiplex operation.)	

Table 7-1 (Cont.)

	Step	Executed By
12.	Observe data on color CRT, precisely locate training data via cursor symbol, and identify to computer via cursor controller.	Operator
13.	Record time, scan count, and element count boundaries for training data; store in disc memory.	Computer
14.	Repeat steps 9 through 13 until all training data have been located; then proceed to step 15.	Computer/ Operator
15.	Rewind data tape recorder.	Operator
16.	Instruct computer via TTY to extract training data and start data recorder in slow playback mode.	Operator
17.	Input data, locate training data according to boundaries identified in step 13, and store training data in core memory.	Computer
18.	Perform radiometric correction of training data via table look-up and restore calibrated data in core.	Computer
19.	Proceed to classification processing coefficient calculation routine.	Operator
II.	Classification Processing Coefficient Calculation	
1.	Instruct the computer via TTY to load COEFFICIENT routine.	Operator
2.	Load COEFFICIENT routine.	Computer
3.	Compute processing coefficients using training data.	Computer
4.	Print processing coefficients via TTY and retain in core memory.	Computer
5.	Proceed to CLASSIFICATION routine.	Operator

Table 7-1 (Cont.)

	III. Classification Processing	
	Step	Executed By
1.	Instruct the computer via TTY to load CLASSIFICATION routine.	Operator
2.	Enter processing instructions via TTY - bands, data disposition (display, film, or CCT).	Operator
3.	Load CLASSIFICATION routine.	Computer
4.	Rewind data recorder.	Operator
5.	Start data recorder in slow playback mode.	Operator
6.	Input data into disc recorder.	Computer
7.	When sufficient data have been entered into disc, begin selected transfer to radiometric correction tables and then to core. (Steps 6 and 7 include the data scan line demultiplexing operation.)	Computer
8.	Classify each pixel and store in core buffer.	Computer
9.	When buffer contains a scan line, or a data record, transfer to display, film recorder, or CCT as instructed in step 2.	Computer
10.	Proceed until all data are classified.	Computer

7.3.5 Data Processor Options

The following options are available to the LCGS to provide the functions described below.

Computer-Compatible Tape (CCT) - Data will almost certainly be provided to users in the form of CCTs for processing on available general-purpose computers. A CCT unit added to the LCGS would permit processing of such data tapes in addition to data received directly from the spacecraft.

High-Resolution Display - A high-resolution display of 1,024 lines on a black and white CRT is required where adequate maps are not available to locate the LCGS site and rough location of training sample data. The high-resolution display provides a wide area display from which the location of training sites can be specified.

Data Grid - A Bendix Data Grid $^{®}$ image measuring unit can be added to the LCGS to permit making precision measurements of data points in an image scene for purposes of determination of geometric correction functions.

High-Speed Classification Processor - A high-speed hardwired classification processor unit can be added to increase the data throughput when performing classification processing. The LCGS, with this processor, would be "transparent" to classification processing with the throughput being dictated by the speed of data demultiplexing, radiometric correction, and display or recording operations.

7.4 LCGS COMPONENTS

This section contains the preliminary specifications of each of the LCGS major components. All system components share common requirements in terms of operating environment and prime power. These common characteristics are listed in Table 7-2. The major components are described in the following paragraphs, each associated with LCGS subsystems.

Table 7-2

Common Requirements of LCGS Components

Environment (unless otherwise specified):

        Temperature: 21 ± 10°C

        Humidity: 20 to 90% RH

        General: A generally dust-free environment must be
                 provided for the electromechanical-optical
                 Input/Output components, particularly the
                 HDDT and film recorder.

Power: The LCGS will be powered by 115 volt ± 10%, 60 ± 1 Hertz,
        single phase power. A total of 6,300 watts are required for
        the basic LCGS without auxiliary equipment.

Shock and Vibration:

        In the interest of low cost, the LCGS uses commercial-industrial
        grade equipment in some cases. For fixed laboratory environ-
        ment application, no special shock and vibration requirements are
        imposed. For transportable or mobile versions of the LCGS,
        special fixtures and padding will be provided during transport to
        permit use of the commercial-industrial grade equipment.

1. Antenna and Feed (for use with fixed spacecraft antenna)

   Antenna type: parabolic dish, 0.55 m diameter, circular polarized feed, gain 31.5 dB, 4.5° beamwidth.

   Weight: 5.4 kg.

2. Antenna and Feed (for use with program-steered spacecraft antenna)

   Antenna type: parabolic dish, 0.15 m diameter, circular polarized feed, gain 20 dB, 16° beamwidth.

   Weight: 5.4 kg.

3. Antenna Mount: elevation over azimuth type with boresight telescope

   Leveling to ± 20 sec.

   Axes orthogonality ± 20 sec.

   Position repeatability and readout to ± 0.025°.

   Antenna and telescope boresighted to ± 0.04°.

   Weight: 55 kg.

4. Preamplifier and Downconverter

   Tunnel diode preamplifier: f_0 = 8.5 GHz, noise figure (NF) = 4.6 dB, gain 17 dB.

   Image rejection notch filter: 20-dB rejection.

   Double-balanced mixer: conversion loss 7.5 dB.

   Local oscillator: stability 1 part in 10^5.

   IF preamplifier: f = 70 MHz, 15-MHz bandwidth, gain 15 dB, NF = 1.5 dB.

   Weight: 3.6 kg.

   Volume: 5,250 cm^3.

   Mounting: mounted on antenna mount.

   Output: coax cable to rack-mounted IF amplifier.

   Environment: temperature controlled package to maintain oscillator stability.

5. IF Amplifier and Bit Synchronizer

IF amplifier: 70 MHz, 3-dB bandwidth of 8 MHz, gain 70 dB, indication of signal strength provided to LCGS operator.

Limiter/discriminator: hard limiting at 0 dBm input, discriminator linear range ±3 MHz.

Bit synchronizer: 8.0-Mbps data input, output 8.0 Mbps NRZ data and data clock.

Size: rack mounting, 14 cm high.

Weight: 9.1 kg.

Power: 150 W.

6. Data Recorder

Heads: two, in line.

Tape: 0.64-cm width, 550-m length.

Tape speeds: record 360 ips, playback, low speed to be determined.

Transfer rate: up to 5 Mbps at 360 ips.

Bit storage capacity: 320 Mb per track.

Size: rack mounting, 28 cm high.

Error rate: 1 per 10^6.

Weight: 14 kg.

Data input: TTL compatible, NRZ data and clock.

Data output: interface to PDP-11 data bus, NRZ format.

7. Film Recorder

Type: framing camera/precision CRT, with indexed three-color filter.

Film size: 102 x 127 mm or larger.

Throughput: color, 1,260 sec per frame max; black and white, 420 sec per frame max.

Resolution: 2.4 KTV lines each with 2.4K pixels minimum.

Size: rack mounting, 1.5 m high.

Weight: 140 kg.

Power: 1,200 W.

Interface: PDP-11 computer.

8. Color CRT Display

Type: solid-state refresh memory, alphanumeric character generator, and color TV monitor.

CRT monitor: 30.5-cm screen, 525-line display.

Refresh memory: 256 lines each with 256 elements, six data bits per element, and one overwrite bit, refresh rate 60 frames per second.

Color assignment: computer-controlled assignment of colors to each 64 words per pixel with complete reassignment of colors in 1/60 sec and without altering content of refresh memory.

Size: rack mounting, 92 cm high.

Weight: 91 kg.

Power: 500 W.

Interface: PDP-11 computer.

9. Digital Clock/Programmer

Digital clock: displays time in hours, minutes, and seconds derived from crystal-controlled time base. Time also output in BCD form at TTL logic levels.

Programmer: switch input time in hours, minutes, and seconds. Programmer input coincidence with digital clock time produces a logic level "1" at TTL logic levels.

Size: rack mounting, 10.2 cm high.

Weight: 4.5 kg.

Power: 100 W.

10. Teletypewriter

Standard ASR-33 TTY interfaced to PDP-11 computer. DEC TTY model LT 33-DC.

11. Digital Computer

Central processor: DEC Model PDP-11/35 or equivalent with 16K core memory, extended arithmetic unit, extender box, and DMA interface cards.

Size: rack mounting, 54 cm high.

Weight: 91 kg.

Power: 1,500 W.

12. Disc Memory

PDP-11 plug-compatible moving head disc memory, 1.25×10^6 words, 75-msec average access time, 10-μsec word data transfer rate.

Size: rack mounting, 31 cm high.

Weight: 23 kg.

Power: 400 W.

7.5 LCGS TRANSPORTABILITY

The LCGS design can be readily made transportable or mobile. The total weight of the basic LCGS is 910 kg without auxiliary support equipment. This auxiliary equipment would vary with LCGS application, but at most would add another 500 kg. These auxiliary equipments are described in Section 7.6.

As a transportable LCGS, the system would be divided into at least three units for transportation – the antenna and antenna mount assembly, the teletypewriter assembly, and the three equipment racks shown in Figure 7-9. The three equipment racks could be palletized where fork-lift capability is available of provided as separable components on wheels where manual handling is required. Special travel support fixture and padding would prevent damage to front panel controls and electromechanical components such as the TTY and data recorder. For installation into existing buildings, a suitable source of the required 6,300 W of 115-V, 60-cycle power is most likely available. Some installations may not have available power; in this case, an engine/generator set must be provided. In this event, it is likely that the equipment will be installed in a site requiring temperature control as well, which will probably double the total power requirements. A suitable engine/generator set will weigh approximately 300 kg and consume about 3 gallons of gasoline per hour.

As a mobile unit, the LCGS and auxiliary equipment can be installed in a converted motor home recreational vehicle. Figure 7-10 shows a mobile unit concept based on a converted motor home. Available units in 23- or 36-ft sizes could adequately contain the LCGS. Available motor homes come equipped with up to 6-kW engine/generators and could be equipped with two such units. Storage for adequate gasoline, water, and waste is already included. Conversion of a motor home to a mobile LCGS would require obtaining stripped models or stripping commercial models of the interior "home" features such as beds, stove, refrigerator, and sink, reinforcing the floor, and adding the LCGS equipment. The motor home bathroom can double as a film processing darkroom. An externally mounted air conditioner would be required to handle the heat load presented by the electronics equipment.

7.6 LCGS AUXILIARY EQUIPMENT

In addition to the receiving and data processing subsystems described in previous sections, the LCGS requires auxiliary equipment which has been mentioned but not previously described. These auxiliary items are briefly described in this section.

7.6.1 Map Library

A map library of the area in which the LCGS operates is a valuable if not necessary auxiliary item used in siting the LCGS and locating training data. Maps to a scale of at least 1:250,000 are required to provide truly effective support; however, they are not available worldwide. World maps at 1:1,000,000 are available and of some value in siting the LCGS and for general planning. A complete set of continental United States maps at 1:250,000 is available from the US Geological Survey, Denver, Colorado, at a cost of about $500. This set comes in a portable rack, which is about 0.75 m wide, 1 m deep, and 1.5 m high and weighs about 25 kg. A complete world map at a scale of 1:1,000,000 is available for $250 from the National Ocean Survey, Washington, D.C. It can be stored in a standard file cabinet requiring about 0.5 m of drawer space.

7.6.2 Engineer's Transit

A standard engineer's transit may be required for LCGS siting as described in Section 7.2.

12136-97

Bathroom/Darkroom

Air Conditioner

Data Processing Subsystem

Storage Area

Rear Compartment Mounted Engine/Generators

TTY

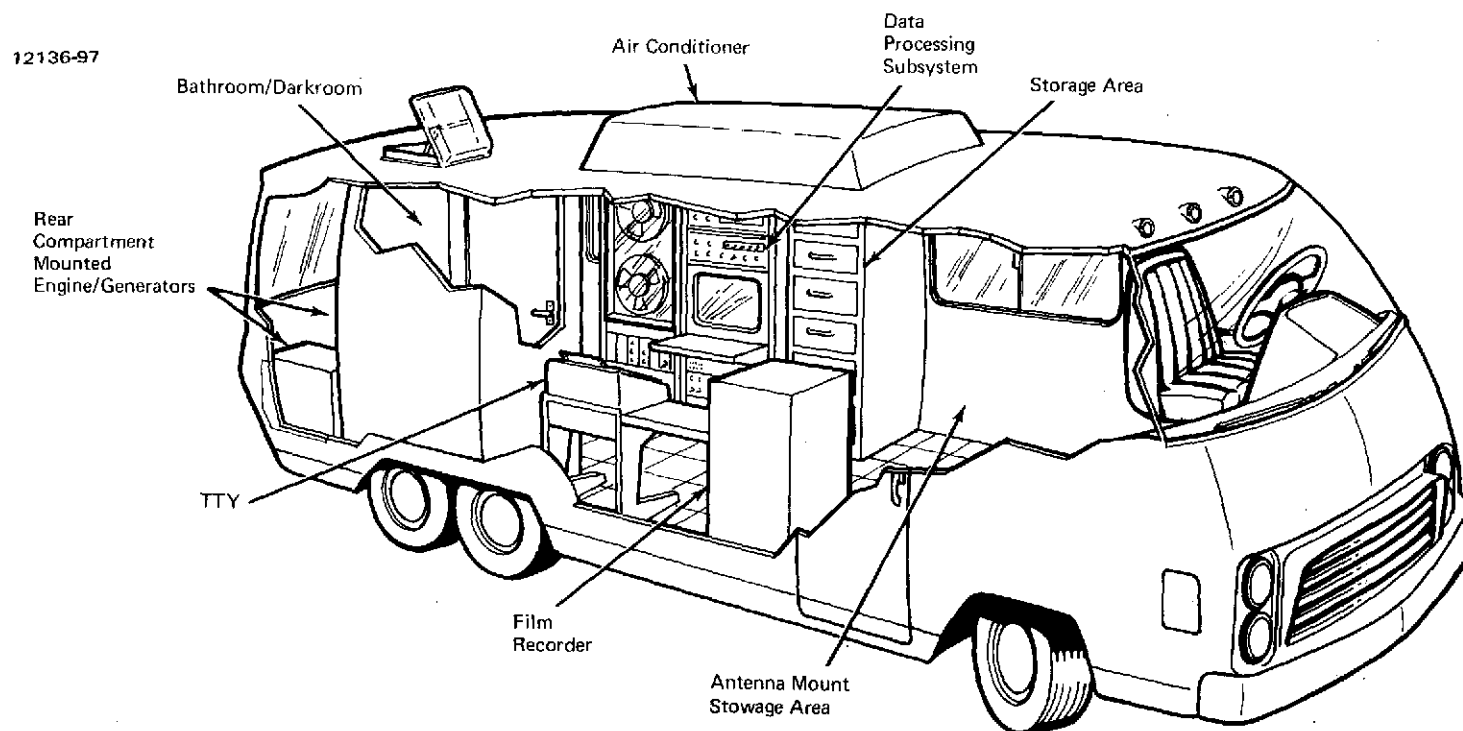Film Recorder

Antenna Mount Stowage Area

Figure 7-10 Mobile LCGS Based on Motor Home Conversion

7.6.3 Film Development and Processing Equipment

The exact film development and processing equipment depends largely on the type of film recorder ultimately chosen for the LCGS. For black and white only recorders, if sufficient light output is available, there are high-resolution dry process films that require no special equipment. For low-light output recorders or for color recorders, auxiliary processing equipment is necessary. The LCGS's total film output per day is very small so that manual tray or small tank processing requires very little equipment, less than found in most amateur photographer's darkrooms. If the mobile or transportable LCGS is to function in remote locations, then the most serious problems are providing an adequate film wash water supply and providing it at the correct temperature.

SECTION 8

CONICAL SCAN AND OTHER SENSOR IMPACT

This section describes the impact on LCGS design if scanners other than the study baseline linear scanner are incorporated into the spacecraft. The principal scanner considered is the baseline conical scanner described in Section 1. Other scanners considered are: (1) high-resolution pointable imager (HRPI), a four-band solid-state "pushbroom" array, (2) six-band opto-mechanical linear scanner with a high duty cycle achieved by active scanning during both directions of mirror sweep, and (3) seven-band opto-mechanical linear scanner with a high duty cycle achieved by a rotating circumferential set of 24 roof mirrors.

8.1   CONICAL SCANNER

The baseline linear and conical scanners are identical in essential parameters such as number of detectors, differing only insofar as one produces linear scan lines and the other curved. Under these conditions, the requirement to process conical scan data impacts only the type of visual data output devices used and the ability to produce linear scan format CCTs.

The color and black and white display CRTs used in the LCGS for display of linear scan data are linear TV-like raster scan devices. The vertical sweep circuits in these displays are not designed for the high-frequency, high-duty cycle operation required to create a conical scan raster. It is estimated that the development of a variable, conical scan raster display, which could display a selected segment of a curved scan line, would cost about $100,000 and each subsequent unit in small quantities would cost $20,000, or about 10 times the cost of the equivalent linear scan display.

In film recorders the impact is not presently as dramatic, primarily because there are no really low-cost film recorders available for either linear or conical scan data. The development of a programmable curved line film recorder capable of recording a selected arc of data would be necessary, incurring a nonrecurring development cost. The difference in recurring costs for this curved line recorder and available linear recorders would not be excessive. However, there is reason to hope that, in the EOS time frame, there will be lower cost film recorders available for linear data.

Linearization of the scan lines on a digital memory and interpolation unit prior to display or film recording would also be prohibitively expensive for the LCGS, although it is feasible for the General Central Data Processing

(GCDP) facility. It was estimated in Volume I of this report that this approach would result in a $160,000 increase in cost - clearly too expensive for the LCGS. For the same reason, it is not feasible to output linear scan CCTs from the LCGS if a conical scanner is used.

In addition to the above, the nonrecurring software development costs for the LCGS would be more for the conical scan data than for the linear scan data. This additional software cost would be to develop the software necessary to program the curved scan line output devices for output of a selected segment of a scan line.

8.2   HRPI SCANNER

The HRPI scanner presents a major problem to the LCGS in the need to radiometrically calibrate 19,200 individual detectors. If a straightforward table look-up procedure is used, about 1.2 million words of memory will be required. Unless some technique can be developed to utilize a low-cost mass memory such as a moving-head disc, this is clearly prohibitive for the LCGS.

8.3   COMPENSATED SINE WAVE LINEAR SCANNER

The compensated sine wave linear scanner, which is a six-band opto-mechanical scanner with high duty cycle achieved by active scan during both directions of mirror sweep, presents a problem to the LCGS concept because five bands each have a detector array containing 132 elements and the sixth band has 33 elements. Processing data in the spacecraft for reducing resolution and buffering requires a large data buffer as does demultiplexing the data on the ground.

8.4   ROOF MIRROR LINEAR SCANNER

The linear scanner with a high duty cycle achieved by a rotating circumferential set of 24 roof mirrors appears to be the most desirable scanner considered with respect to the LCGS concept. The LCGS described in Section 7 is applicable to this scanner without modification.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations resulting from this study are as follows:

1. The concept of adding some level of sophistication to the spacecraft to permit the design of a small local user Low-Cost Ground Station (LCGS) was concluded to be feasible, practical, and useful. A preliminary design concept for the spacecraft multispectral scanner (MSS) processor to support the LCGS was defined. It is recommended that this concept be incorporated into the future EOS spacecraft design.

2. A small local user ground data system was defined that is low in cost, provides data directly to the user, provides more timely data than obtainable from the GCDP facility, and permits the local user to operate interactively with the system for data collection and processing. Based on this definition, a feasible implementation of an LCGS was defined and specified in preliminary form. It is recommended that this LCGS design be detailed, developed, and placed into experimental operation under the EOS program.

3. The LCGS has three basic characteristics which are considered major attributes: (1) direct user interface, (2) immediate data availability, and (3) a level of data security or privacy resulting from directive antennas. One basic characteristic, selected scene data, can be considered both an attribute and, in some cases, a limitation.

4. Assuming that horizon-to-horizon data communications are not required, designs are possible for low-cost data communication subsystems which can support the LCGS with meaningful, useful data rates. There are no critical or long-lead development items required for the data communications subsystem.

5. The data volume which must be processed by the LCGS is very substantially less than that to be processed by the GCDP facility. Implementation of the data processor for the LCGS therefore can be based on a low-cost minicomputer rather than the special-purpose computation hardware supported by a minicomputer required for the GDPS.

6. One major cost component of the LCGS is the data recorder. Development of a lower cost recorder would permit significant reduction of the LCGS cost. One attractive possibility is the modification of a commercial video-cassette magnetic tape recorder to accept high-data-rate data and to operate at a reduced playback data rate for computer interface. It is recommended that an investigation be conducted to determine the feasibility of such a development.

7. Another major LCGS cost element is the data film recorder. It is recommended that an investigation be undertaken to investigate the development of a low-cost film recorder more directly applicable to the LCGS need.

8. Although there are LCGS components that could be improved or reduced in cost with on-going development, there are no inherently necessary critical or long-lead development items required for the LCGS data processing subsystems.

9. The LCGS design can be configured so that it can be readily adapted to fixed, transportable, or mobile operation. An implementation of a mobile concept based on installing the LCGS equipment in a modified motor home recreational vehicle appears feasible and practical.

10. The impact of conical versus linear scan data format on the LCGS is primarily on the visual data output devices used in the LCGS and the ability to produce linear scan format CCTs from conical scan data. Conical scan data format would require the development of a programmable curved scan line data display and would require a similar film recorder. It is estimated that the display development would cost about $100,000 and each CRT display unit would cost about $20,000, or about 10 times the cost of the linear display. Presently available curved scan line film recorders are about equal in cost to available linear scan recorders, but there are reasons to believe that the linear recorders could be significantly reduced in cost, unlike the curved line recorders. Linearization of the scan lines in a digital memory and interpolation unit would be prohibitively expensive for the LCGS. For this same reason, it is not feasible to output linear scan CCTs from the LCGS if a conical scanner is used.

11. The HRPI scanner presents a major problem to the LCGS in the
     need to radiometrically calibrate 19,200 individual detectors.
     It is recommended that techniques other than the normal straight-
     forward table look-up procedure be investigated which may
     permit HRPI use with the LCGS.

12. The compensated sine wave linear scanner does not appear
     compatible with the LCGS concept because of the very large
     demultiplexing problem presented by scanning five 132-element
     detector arrays in a single sweep of the scanning mirror.

13. The roof mirror linear scanner is the scanner most compatible
     with the LCGS concept. The LCGS design concept resulting from
     this study is directly applicable to this linear scanner.

14. Consideration should be given to orbits which result in the 24-hour
     orbit displacement of more than one swath to maximize the LCGS
     coverage with sensor lateral offset and a steerable spacecraft
     antenna.

APPENDIX A

SYSTEM NOISE TEMPERATURE

Radio frequency (RF) link calculations throughout Section 3 are for a single specified system noise temperature T_S of 780°K. This value is for a tunnel diode preamplifier. This appendix derives T_S from receiving system parameters depicted in Figure A-1.
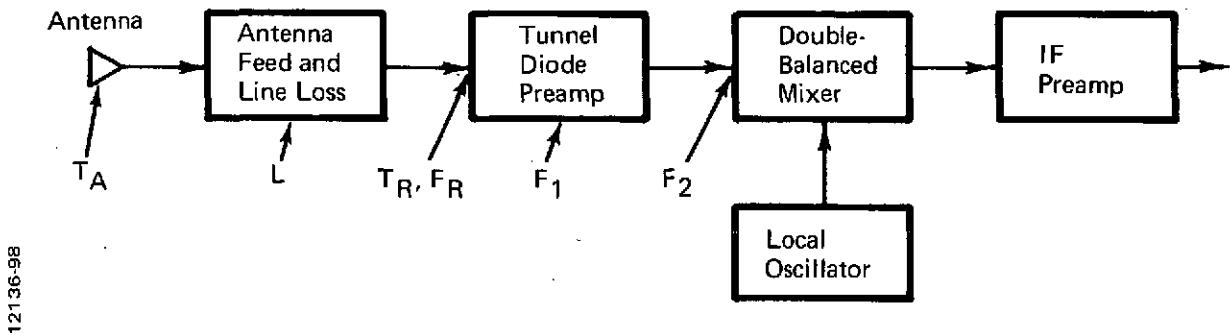

Figure A-1 System Noise Temperature Model

$$T_S = T_A + (L-1)\ 290°K + LT_R$$

$$TR = (F_R -1)\ 290°K$$

$$F_R = F_1 + \frac{F_2 - 1}{G_1}$$

where

T_S = system noise temperature referenced at the antenna feed point

L = loss between antenna feed and preamplifier

T_A = antenna noise temperature referenced at the antenna feed point

T_R = receiver noise temperature at input to RF preamplifier

F_R = receiver noise figure at input to RF preamplifier

F_1 = noise figure of RF preamplifier

F_2 = noise figure of double-balanced mixer, including noise contribution of IF preamplifier input

G_1 = gain of RF preamplifier.

A-1 (II)

With a gallium antimonide tunnel diode as a preamplifier, a preamplifier noise figure $F_1 \leq 4.6$ dB may be achieved with a preamplifier gain $G_1 \geq 17.0$ dB. With a Schottky diode double-balanced mixer followed by an IF preamplifier having a noise figure of 1.5 dB, a mixer noise figure $F_2 \leq 9.0$ dB is readily available. This is the single sideband value; image noise rejection via a filter in the RF preamplifier is presumed. Using the above values, the computed receiver noise figure $F_R \leq 4.8$ dB. A value of $F_R = 5.0$ dB is used in subsequent calculations.

Referring to Hogg and Mumford, "The Effective Noise Temperature of the Sky," The Microwave Journal, March 1960, antenna noise temperature at 8.5 GHz with the antenna pointing 30° above the horizon is $\approx 7°$K. Ground contribution due to feed spill-over and sidelobes down 15 dB is $\approx 290°$K/ $31.6 \approx 10°$K. Therefore, $T_A \approx 17°$K. Loss in the antenna feed and line loss between antenna and RF preamplifier may be held to $L \leq 0.3$ dB. Using the above values, the computed value of system noise temperature $T_S = 708°$K. Note that a constant value of antenna temperature $T_A = 17°$K has been assumed for all conditions computed in Section 3. The 17°K value is based upon the antenna pointing $\theta = 30°$ above the horizon. This corresponds to a distance $s \approx 1,000$ km between the ground station and the spacecraft subpoint. Most computations in Section 3 are for $s < < 1,000$ km; therefore, T_S is somewhat less than 708°K. One set of computations, for $s = 1850$ km, corresponds to $\theta = 12.4°$ and $T_A \approx 28°$K. Thus, $T_S \approx 719°$K, which is only 0.06 dB greater than the value used in the computations.

The improvement in system noise temperature achievable, by using a noncryogenic parametric amplifier as an RF preamplifier in place of a tunnel diode, is summarized as follows. The range of noise temperatures of parametric amplifiers available today is from about 1.3 to 2.5 dB at a frequency of 8.5 GHz, with at least one manufacturer claiming 1.1 dB. These are for temperature-stabilized or thermoelectrically cooled units, and not cryogenically cooled. Typical single-stage gain is 15 dB. As a further improvement, the mixer IF preamplifier noise figure (single sideband) can be reduced to 6.0 dB. (One manufacturer claims that 6.5 dB can be provided at this time.) The following values are expected to be well within the state of the art and therefore representative of economical parametric receiver hardware in the EOS ground station time frame:

$F_1 = 1.3$ dB

$G_1 = 15.0$ dB

$F_2 = 6.0$ dB

These values result in a receiver noise temperature T_R = 129°K. With L = 0.3 dB and T_A = 17°K, T_S = 176°K. This is a 6-dB improvement over the 708°K value for a tunnel diode preamplifier used in all computations in Section 3.

APPENDIX B

ERTS/EOS ORBITAL PARAMETERS

B. 1   INTRODUCTION

ERTS and EOS are placed in sun-synchronous circular orbits and repeat their scanning patterns exactly over a period of several days. The nominal swath width in each case is 185.2 kilometers (100 nautical miles) and the target sidelap between adjacent swaths is 10%. Altitudes to be considered lie within the range of 300 to 1,200 km. The requirement to repeat the scanning pattern means that the total number of orbits in the repeat period must be integral, which in turn allows only a finite number of discrete solutions to exist for any given ranges of parameters. Figure B-1 and the equations in Figure B-2 enable the rapid determination of the precise orbital parameters that most closely match given approximate requirements.

1.   Orbital Altitude at Equator:

$$h = 42,241.2 \ [N/n]^{2/3} - 6,378.2 \ \text{Kilometers}$$

2.   Orbital Period:

$$T = 1,440 \ [N/n] \ \text{Minutes}$$

3.   Sidestep Between Overlapping Scans at Equator:

$$\text{Sidestep} = 40,075.2/n \ \text{Kilometers}$$

4.   Orbital Inclination for Sun-Synchronism:

$$i = 90 + \sin^{-1} \ [73.9 \ (N/n)^{7/3}] \ \text{Degrees}$$

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Figure B-2   Orbital Parameters in Terms of N and n

B. 2   DERIVATION OF FIGURE B-1

For any practical ERTS/EOS orbits, the sun-synchronous requirement leads to an orbital inclination within the range of 90° to 100° (see Section B. 2. 2). The track of the satellite at the equator is therefore approximately north-south, with the swath width approximately east-west.
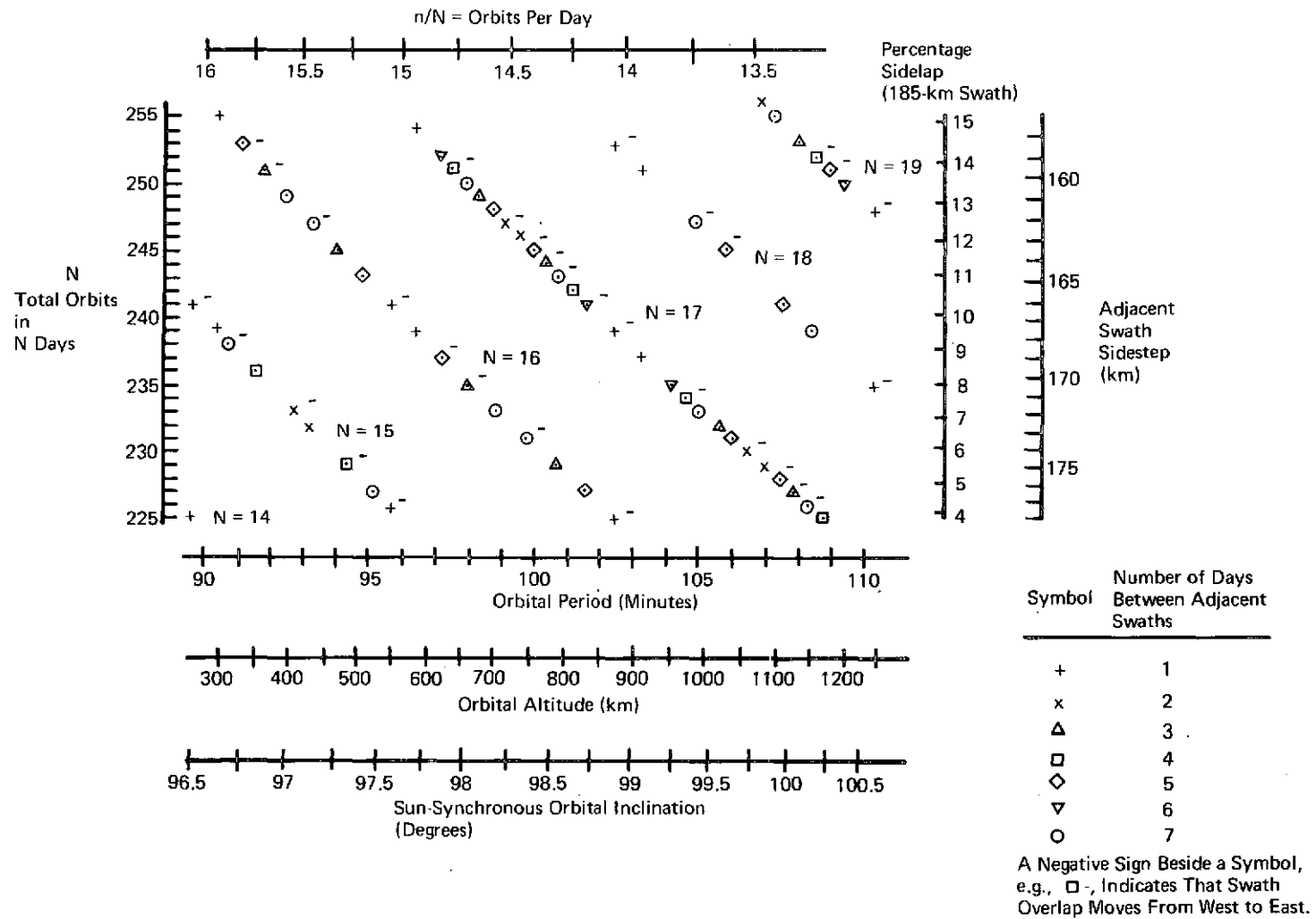
n/N = Orbits Per Day

16   15.5   15   14.5   14   13.5

Percentage Sidelap (185-km Swath)

255

250

245

N
Total Orbits
in
N Days   240

235

230

225

N = 19

N = 18

N = 17

N = 16

N = 15

+ N = 14

15
14
13
12
11
10
9
8
7
6
5
4

160

165

170

175

Adjacent
Swath
Sidestep
(km)

90   95   100   105   110

Orbital Period (Minutes)

300   400   500   600   700   800   900   1000   1100   1200

Orbital Altitude (km)

96.5   97   97.5   98   98.5   99   99.5   100   100.5

Sun-Synchronous Orbital Inclination
(Degrees)

Symbol	Number of Days Between Adjacent Swaths
+	1
×	2
Δ	3
□	4
◇	5
▽	6
○	7

A Negative Sign Beside a Symbol,
e.g., □ -, Indicates That Swath
Overlap Moves From West to East.

Figure B-1   Orbital Parameters

B-2 (II)

Let the satellite make exactly n orbits in the pattern repeat period of exactly N days, and let adjacent overlapping scans be made at intervals of approximately p days (by definition, p is to be integral; an adjacent scan therefore must occur after a period which is slightly less than or slightly greater than 24 x p hours).

Since the earth is scanned completely by n orbits in N days, then:

$$\text{Sidestep at Equator between Adjacent Scans} = 2 \pi R/n \tag{B-1}$$

$$\text{Sidestep at Equator between Successive Orbits} = 2 \pi RN/n \tag{B-2}$$

where

R = equatorial radius of earth

= 6,378.165 km.

If the overlapping scan after a period of approximately p days falls to the west of the first scan, then:

$$[2 \pi RN/n] \times [\text{Integral Part of } (1 + pn/N)] = 2 \pi Rp + 2 \pi R/n \tag{B-3}$$

$$\text{i.e., Int}[1 + pn/N] = [pn + 1]/N \tag{B-4}$$

$$\text{i.e., Int}[1 + pn)/N + (N-1)/N] = [pn + 1]/N \tag{B-5}$$

Thus, $[pn +1]/N$ integral defines all possible solutions.

If the overlapping scan falls to the east, then:

$$[2 \pi RN/n] \times [\text{Integral Part of } (pn/N)] = 2 \pi Rp - 2 \pi R/n \tag{B-6}$$

leading to $[pn-1]/N$ integral as the definition of all possible solutions in this case.

B.2.1   Probable Ranges of n, N, and p — If the swath width is S km and a fractional sidelap α is required at the equator, then:

$$n = 2 \pi R/S (1 - \alpha) \tag{B-7}$$

where

R = 6,378.165 km.

Since S is nominally 185.2 km and the target α is 0.1, the preferred value of n is 240 or 241. If α can be allowed to vary between, say, 0.10 ± 0.06, then the extreme acceptable values of n are 225 and 255.

Since the satellite makes exactly n orbits in exactly N days, the satellite orbital period must be:

$$T = 1,440 \ (N/n) \ \text{minutes} \tag{B-8}$$

For a circular orbit with equatorial altitude h, the period is given by:

$$T = (2\pi/60) \ \sqrt{(R + h)^3/MG} \ \text{minutes} \tag{B-9}$$

For the earth, the value of MG is 3.986032×10^5 km^3/sec^2 and R is 6,378.165 km, hence:

$$T = 1.65866 \times 10^{-4} \ (6,378.165 + h)^{3/2} \ \text{minutes} \tag{B-10}$$

where

   h is in km.

Combining Equations B-8 and B-10 gives:

$$N/n = 1.15185 \times 10^{-7} \ (6,378.165 + h)^{3/2} \tag{B-11}$$

Varying h from 300 to 1,200 km and n from 225 orbits gives a range of N from 14 to 19 days.

The permissible values of p range from 1 to (N-1), but it is assumed that in practice there is not much interest in periods over one week, i.e., $P_{Max} = 7$.

The combinations of values of n, N and p (within the ranges outlined above) which make (pn $\pm$ 1)/N integral have been determined and are plotted against orbital period (Equation B-8) in Figure B-1. Different symbols have been used to denote the value of p and the direction of stepping of overlapping scans. Also plotted in Figure B-1 are orbits per day (n/N), orbital altitude (Equation B-11), sidelap (Equation B-7), sidestep (Equation B-1), and orbital inclination for sun-synchronism (Equation B-12, see Section B.2.2).

B.2.2 Sun-Synchronism – In a sun-synchronous orbit, the rate of gyro-
scopic precision of the orbital plane due to the oblate shape of the earth ex-
actly equals the mean angular motion of the earth about the sun, i.e., 360°
per year, or 0.9856° per day. The plane of the orbit thus makes one revo-
lution relative to the earth in exactly 24 hours. (This is a basic assumption
in all the previous sections.) The direction of motion of the earth-sun line
due to the motion of the earth about the sun is from west to east, and to
match this motion the satellite orbit must be retrograde, i.e., revolve against
the rotation of the earth. Per D. King-Hele[*], the relationship between or-
bital inclination and orbital altitude for sun-synchronism is:

$$9.97 \ (R/R + h)^{3.5} \cdot \text{Cos } i = -0.9856 \text{ degrees/day} \qquad (B-12)$$

where

$R = 6,378.165$ km

h = equatorial altitude in km
     (assuming circular orbit)

i = inclination of orbit.

Since i, for values of h from 300 km to 1,200 km, lies in the range of 96° to
100°, active (i.e., daylight) passes over the United States will always be
from a few degrees east of north to a few degrees west of south, or from a
few degrees east of south to a few degrees west of north, depending upon the
chosen orientation of the orbit relative to the sun. The ERTS, and presum-
ably EOS, uses the north-to-south mode.

B.3 METHOD OF USE

The method of use of Figures B-1 and B-2 is to enter Figure B-1 with
the approximate desired values of one or more parameters, determine the
integral values of n and N for the nearest acceptable solution, then work back
from N and n through the equations in Figure B-2 to obtain the precise orbi-
tal parameters. Thus:

B.3.1 Example 1

The latest altitude quoted for EOS is 914.2 km. Figure B-1 shows
that there are two solutions at or close to this altitude, as follows:

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[*] D. King-Hele, Satellites and Scientific Research, Routledge and Kegan Paul,
London, England, or Dover, New York, 1960.

n	N	p	Direction of Sidestep
237	17	1	East to West
251	18	1	East to West

Substituting in Equation 1 in Figure B-2 gives an altitude of 914.23 km for (237, 17) and 912.62 km for (251, 18). The repeat period is thus 17 days with approximately 8.7% sidelap at the equator.

B.3.2   Example 2

For study purposes, we have assumed an orbital altitude of 735 km at the equator. Figure B-1 shows that the nearest solutions are:

n	N	p	Direction of Sidestep
231	16	7	West to East
246	17	2	East to West

There is no solution anywhere near this altitude giving a 1-day sidestep. The preferred solution is (246, 17) giving a 162.9-km sidestep at the equator every second day with approximately 12% sidelap. From Equation 1 in Figure B-2, the precise altitude at the equator is 735.26 km.